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ARMY ORDNANCE TODAY*

BY

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I. INTRODUCTION

During the past many years I have been invited to speak on numerous occasions at various institutions, societies, colleges, and universities throughout the country. Of all of these, none has given me more pleasure than this invitation to address the members of Franklin Institute, which is one of the country's oldest and foremost institutions of its kind.

Having been established in 1824 for the study and promotion of the mechanic arts and applied sciences, there has always been a common bond of interest between Franklin Institute and Army Ordnance.

During the past several years Franklin Institute has contributed much to Ordnance, particularly in the field of design. It is continuing to contribute a great deal at present. Currently, I believe, it is employed on five separate development contracts which amount to approximately one million dollars.

Some of Franklin Institute's achievements have been very noteworthy indeed, and it was no empty gesture when we presented the Institute with the Ordnance Distinguished Service Award in September, 1944. It was instead in grateful recognition of outstanding and meritorious engineering advisory services in the design, manufacture, and maintenance of Ordnance materiel.

II. ORDNANCE OBJECTIVES

In my everyday work and travels, I meet many people with vague and obscure notions about the Ordnance Corps, what it is, what it does, and what its responsibilities and objectives are.

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I have always liked the definition once given by a former Chief of Ordnance, who said, "Ordnance produces everything that shoots, is shot, and rolls."

That is a pretty simple definition of the functions of the Ordnance Corps—no doubt it is an over-simplification—but only when you know about all the things that Ordnance does, do you appreciate how good this definition is.

Ordnance has the responsibility for development, production and procurement, storage, issue and maintenance of all the Ordnance materiel used by the Army. It also has this responsibility in many cases for supplying materiel to the other services—the Navy and the Air Force.

And, when I speak of Ordnance materiel, I am referring to all small arms, that is, rifles, side arms, and machine guns; to artillery of all kinds—to man-portable artillery—mortars, rockets, recoilless rifles; to field and heavy artillery; to the larger type rockets; to ammunition for all of these; to mines, grenades, and pyrotechnic devices; to fire-control devices for aiming and directing guns; to armored vehicles; trucks; and to packing equipment and materials for all of these many items.

The list, indeed, includes everything that shoots, is shot, and rolls. Incidentally, we can broaden the definition a little when there is included Ordnance responsibility for furnishing aircraft to the field forces.

Ordnance, today, is one of the biggest businesses in the world. In its shopping list there are more than 400,000 items.

The Ordnance Corps has 103 installations under its jurisdiction within the continental limits of the United States and employs approximately 163,000 persons.

Perhaps you will get a better idea of the size and scope of the job by considering that of a total defense and foreign military aid budget of approximately 65 billion dollars for the current fiscal year, we in Ordnance are handling 15 billion dollars of the over-all program.

Our objectives and areas of responsibility have been changed somewhat from time to time since the Corps was officially established as a separate branch of the Army in 1812.

Today, in broad terms, our objectives in Army Ordnance are:

1. To produce and/or procure new, modern Ordnance materiel for the expanding Army, Navy and Air Force.

2. To reconstitute our reserve stocks in storage and in the hands of troops—world wide.

3. To continue and increase our progressive research and development program.

4. To get industry into production on a broad base, so it will be in a position to expand rapidly in the event of an all-out mobilization.

III. OUR PROBLEMS TODAY

The problems and objectives of Army Ordnance today are much the same as they were ten years ago. Actually, there are some very fundamental differences which make some aspects of our present job even more complex.

Ten years ago we were concerned with getting all-out production in as short a time as possible. Today, our problem is complicated by our two-fold production goal. One phase of that goal is the actual procurement of a specific amount of material. The other is the establishment of a broad industrial base capable of multiplying our present measured output many times in the event of mobilization.

Building up and maintaining our military strength and preparedness under partial mobilization, with a minimum disruption to the civilian economy, calls for administration and leadership of a very high order; transition from a peacetime to a wartime economy in an all-out emergency would not be as difficult as this transition from peacetime to partial mobilization. An all-out emergency would lessen some of the problems we are now having.

Our problems today are different from the past also in respect to the type of weapons. Changing concepts of warfare have dictated changes in the characteristics of the weapons which we produce.

The stabilized type of warfare waged in World War I, in which troops were pinned down in the trenches and fought at close-range, gave way in World War II to a type of warfare in which the emphasis was on mobility, longer range, and increased firepower.

It has long been realized by military tacticians that the advantage in combat lies with that side that can get in the first blow and keep up the blows. Maximum attainable manueverability and mobility provide the other great assets.

These prime considerations and military requirements have been given assistance of inestimable value by the developments of modern technology. In fact, modern technology has revolutionized our concepts of warfare and the means by which it is waged.

By the same token, just as "necessity is the mother of invention," the needs of our armies in combat have given impetus to exploration and research in fields of pure and applied science that have made vast contributions to industry, and have had a profound effect on our daily living.

IV. THE FUNCTIONS OF ORDNANCE

Now, in identifying the role of the Ordnance Corps in the defense program, let me tell you a little about the over-all functioning of the Department of Defense.

First, the Joint Chiefs of Staff decide what forces are needed for the defense of our country at home and abroad. They then inform the

Army, Navy, Air Force, and Munitions Board what those forces are . . . in what quantity and at what time they will be required.

Each of the three military services then takes the task assigned to it by the Joint Chiefs of Staff, breaks it down into units—so many divisions, so many air wings, so many ships—and translates these units into all of the 2.5 million items needed to equip and maintain those troops or air wings or ships in accordance with the plans of the Joint Chiefs of Staff. As a further step, each service translates those guns, or tanks, or planes, into tons of steel or copper or aluminum, or whatever is required.

Each service then determines when that steel or copper or aluminum will be needed by its contractors.

Then the Munitions Board goes to work to assemble these requirements, to make sure that they are actually needed, to eliminate duplication, to squeeze the water out, to time-phase the requirements, and to see that materials and facilities are available to produce them. The Munitions Board, in a few words, is responsible for the supervision of industrial mobilization for the Armed Forces.

The Ordnance Corps, in accomplishing its mission of supplying the many items of Ordnance to our troops, has three major operating functions:

1. The research and development function.
2. The industrial function—to produce and procure.
3. The field service function—to store, issue and maintain.

This work begins when the Army Field Forces determine the characteristics of the Ordnance materiel needed to fulfill the requirements of their combat mission.

Any new weapons or types of weapons or equipment, or any improvements to any of these, then go through the research and development stage of thorough experimentation and testing before standardization.

The Research and Development Division coordinates, supervises, and directs all research and development activity of the Ordnance Corps. It has authority to make contracts, to control all research and development funds, and to do all things necessary to improve standard weapons and equipment as well as to develop new ones.

Its staff of Ordnance designers, assisted by many civilian scientists, constitutes a nucleus of some of the finest talent of its kind in the world.

A step, taken last June, which gives promise of great significance to the field of research and development, is the activation of the Office of Ordnance Research at Duke University, Durham, North Carolina. From that office, which is a permanent establishment, is being directed and coordinated a nation-wide Ordnance research program.

Serving as a clearing-house for basic research of potential interest to the Ordnance Corps, the Office of Ordnance Research has invited

research institutions throughout the nation to submit proposals for basic research projects. All proposals are evaluated and contracts are awarded for those of particular merit.

This program entails the placement of basic research contracts with colleges, universities, and other research institutions throughout the nation, the purpose of which is to stimulate the accumulation of knowledge of fundamental principles in the fields of physics, chemistry, mathematics, and the engineering sciences. The impact of the results of this basic research bears directly on the development of new weapons, materials, and design principles of interest to Ordnance.

It is contemplated that these projects will be integrated into various research institutions' programs and used in training graduate research students. In this way, we hope to build up a corps of young scientists throughout the United States with a knowledge and appreciation of the technological problems of the Army Ordnance Corps.

As I have already said, the function of the Industrial Division is production and procurement after an item of Ordnance has gone through the research and development stage and has become standardized.

In all our production and procurement operations, careful planning is of the utmost necessity.

It is vitally necessary to our survival as a nation that we maintain the strongest possible posture for defense, and to do this it is essential that our defense production be dispersed over the broadest possible base.

With the unsettled conditons in international relationships that existed after World War II, our production planning was augmented by retaining some dozens of wartime plants which we kept in a standby status. These were primarily for the manufacture of various chemicals and other components of explosives, as well as the explosives themselves, and for ammunition and bomb loading.

Nowhere in our peacetime production are duplicates of these plants to be found, so it was important that as many as possible of them be kept in condition to start operations on short notice. Since the outbreak in Korea about 30 of these plants have been reactivated.

For the same reasons, we retained in reserve storage large quantities of machine tools needed to put these plants in operation. The comparative speed with which they are getting into operation proves that the selection and storage of these tools was a wise move.

The heart of our production is our system of mission arsenals. In peacetime these arsenals keep alive the art of munitions making through continued research and engineering and through pilot lines set up to produce test models in small quantities. In this way they are able to work the "bugs" out of manufacturing processes and keep up with all the latest advances in tooling and other industrial arts. Thus, with the advent of war, these small lines can be rapidly expanded to fill the production gap while industry is getting under way. It is from the

mission arsenals that the conversion of our industries can be directed and guided to a flood-tide of war production.

The history of this system of mission arsenals, sometimes called the old-line arsenals, in a sense reflects the history of the growth and development of the United States of America. All of them were established as the need arose and were located as dictated by considerations of strategy, facilities for transport, availability of supplies, and the presence of manpower skilled in those trades necessary for the manufacture of arms and the munitions of war. They became arsenals, largely, for reasons geographical and economic. Up to the beginning of World Ward II, there were six of these old-line arsenals; Springfield, established in 1794; Watervliet, in 1813; Watertown, in 1816; Frankford, here in Philadelphia, 1816; Rock Island, in 1863; and Picatinny, in 1879.

The advent of World War II emphasized the need for additional arsenals, and during the war, two new ones, Redstone Arsenal at Huntsville, Alabama, for rockets and guided missiles, and the Detroit Arsenal at Detroit, Michigan, for tank and automotive equipment, began to evolve, though they were not officially organized and designated as arsenals until afterwards.

All of these arsenals have functions which, collectively, run the gamut of engineering, research, and production of Ordnance materiel of all kinds.

Because the capacities of these arsenals cannot begin to cope with the production requirements of a World War and since emphasis, for many years, has been heavily on the side of engineering and research, we always have to turn to private industry for the bulk of our actual war production. Basically, in turning to private industry, our procurement operations are being handled by decentralization from Washington to 14 Ordnance Procurement Districts. Insofar as Ordnance items are concerned, no procurement is done in Washington. The Pentagon manufactures nothing.

In addition to the Districts and Arsenals, we have recently established commodity centers for certain Ordnance materiel: the Ordnance Small Arms Center at St. Louis, which has charge of procurement and production supervision of all small arms ammunition; the Ordnance Ammunition Center at Joliet, Illinois, which has charge of procurement and production supervision of all artillery ammunition, except some development types in limited quantities; and the Tank-Automotive Center in Detroit, which is responsible for procurement and production supervision of all armored and automotive vehicles.

Together, our manufacturing arsenals and these recently established commodity centers are charged with nation-wide procurement of each item of Ordnance materiel, and both work through the Ordnance Districts. As all of these installations must rely upon industry for the great bulk of their procurement, they are as a consequence, doing busi-

ness today with thousands of industrial plants all over the country. In addition to their procurement functions, and correlation of the procurement requirements of the arsenals and centers with lists of potential bidders, the districts administer the contracts after they are signed. When the items on contract are inspected and accepted by the Ordnance District, the bills are paid. Quality of product is stressed throughout.

In all of these procurement activities, Army Ordnance places great stress upon an equitable distribution of the procurement load. This distribution runs to the geographical factor and, what is of greater importance, to all sizes and types of business qualified to produce for Ordnance.

Much has been said about small business and I can assure you that we cannot meet our requirements without small business. Some publicity is given to the small business angle to the extent that it might be presumed that there is some resistance on the part of Government purchasing agencies to use small business. Such is not the case.

When we have a big job to be done, like building a new tank or a big new gun, naturally we must turn to a big firm that has the production facilities, the technical know-how, and all the other resources at its command necessary to do the job. This does not necessarily mean that the big firm will do the job alone. It means that it is the one which gets the prime contract. It is necessary, as all of you know, to farm out a large percentage of the job on sub-contracts to small firms capable of producing some of the innumerable component parts. When we have a job of less magnitude that can be done by one or several small business concerns, we prefer to let contracts to firms of that size. For the average tank, it is estimated that as many as 3000 sub-contractors from all parts of the nation are employed in every procurement.

The operations of the Field Service Division are in themselves an enterprise of vast proportions. Consider for a moment the tasks involved in transportation, maintenance, rebuild, and storage of all these items of Ordnance which have been produced. The network of maintenance and repair shops, of depots with their supplies and inventories of spare parts, must cover all those areas where our Ordnance materiel is in use—and this means that it is world-wide—right up to the front lines on the battlefield.

In our enormous rebuild program we have reclaimed much of the Ordnance materiel from the battlefields of World War II, disassembled it, and rebuilt it, just like new. This has amounted to a de-manufacturing and a re-manufacturing process, both as to type and magnitude not normally found in industry. Under "Operation Roll-Up," the name given to our rebuild program begun in 1948 in the Pacific, enormous quantities of Ordnance materiel that had had to be virtually abandoned because of our too-rapid demobilization, have been recovered

at savings to the taxpayer that is measured in billions of dollars. Such materiel as was considered salvageable was brought from islands all over the Pacific to Japan where the rebuilding operations were performed, largely by Japanese personnel which we were required to train. By last May more than 30,000 Japanese workers and approximately 850 American personnel, both military and civilian, were directly employed on the project which has been stepped-up with the outbreak in Korea. This program has provided, for example more than 50,000 general purpose trucks, 700,000 small arms weapons, and 700,000 tires and tubes for the use of the United Nations forces in Korea. These vehicles were delivered to the United Nations Forces at a highly critical time in our history when vehicles in the required quantities were available from no other source.

The importance of this rebuild program to our forces in Korea cannot be over-estimated and the savings in transportation and ship tonnage from the United States has been appreciable.

V. MODERN TREND

Having examined the operation and functioning of this gigantic enterprise which is the United States Army Ordnance Corps, let us consider some of the things it is producing today.

Since most of you are no doubt familiar with many of these items as used in World War II—jeeps, tanks, trucks, and guns—at least in a general way, you probably would prefer to hear more about developments in the modern trend.

You may well ask—"what is the modern trend in Ordnance materiel?"

Going back to that definition in which Ordnance is described as "producing everything that shoots, is shot, and rolls," I might say that the modern trend, in a general way, is toward production of Ordnance materiel that shoots faster and with greater impact, is shot to a greater distance, and rolls over difficult terrain with less maintenance involved.

In other words, the modern trend has been toward greater firepower, greater range, and greater mobility with durability.

In a large measure, our efforts of the last few years have been concentrated on improvement and more improvement—on intensifying our exploration and experimentation in fields with which we have already long been concerned.

Some of our present areas of exploration, which on the surface appear to be entirely new and radically different, are but extensions of efforts we have long been making. They, for the most part, are logical developments in a long and evolutionary process.

Our most startling new developments today have been largely the result of learning new applications or new combinations of old laws and old principles, already long known and understood. Take, for example,

rockets and guided missiles. Few subjects in modern times have excited greater interest or more speculation. The development of supersonic rockets has resulted in speculation in the press about push-button warfare, rockets to the moon, earth satellites, and other fantastic stories of that kind. Let me emphasize here tonight that our experimentation and research in Ordnance is on a much more realistic and practical level. While the time may come when results bordering on the fantastic will be achieved, the anticipation of the fantastic has exceeded our aims and accomplishments.

The primary principle back of rockets was expressed in Newton's Laws of Motion back in the seventeenth century, and free rockets were used by the Chinese as long as 700 years ago. Their employment continued through the centuries until rifled guns were introduced in 1860 when they fell into disuse because they could not compete with the increased accuracy of rotating projectiles—and rockets still are not as accurate.

Interest in free rockets was renewed before World War II because of their advantage over artillery in that no heavy gun or mount is necessary. Only a light-weight, open tube or a pair of hooks, like a bomb rack, are required for launching, though some fire control is essential for proper accuracy. In this class we have such rockets as the bazooka which was developed by this country as a weapon with which a soldier could destroy a tank single-handedly. When hostilities broke out in Korea and our troops came up against the heavy armor of the Russion T-34 tank, we supplied them with a larger rocket launcher, one that was 3.5 inches in diameter as compared to the 2.36-inch model with which they were then equipped.

We have also developed field artillery type rockets which supplement rather than supplant conventional artillery. During the war, multi-tube launchers, capable of firing as many as 60 rockets without reloading, were installed on tanks, vehicles, and boats, and used to saturate area targets such as beach-heads, strong points, and service installations.

From free rockets to guided missiles was a logical development since a guided missile is a rocket or jet-propelled missile with a built-in mechanism for aiming and guidance.

We have done a great deal in the field of guided missiles and we expect to do a great deal more. The extent of our research and the progress we have made are, of necessity, of a classified nature. However, I can tell you that the area of research encompasses all possible applications. Just where all this will eventually lead us and just what effect it may have on future warfare, no one can accurately predict. But it is plainly indicated that pursuit along these lines will have the eventual effect of extending the reach of our ever-increasing striking power and the area upon which that power can be employed.

Other than rockets and guided missiles—less spectacular perhaps, but certainly of no less significance—are our developments in the field of small arms and artillery pieces. The trend in these is, as it has always been, toward greater efficiency, greater firepower, and a decrease in weight. This means greater ease in handling and maintenance, and greater effectiveness on the battlefield. One of our most recent developments in the field of small arms has been the new light rifle that can be fired single-shot or automatically.

This new light-weight .30 caliber rifle, which I mention, has as yet not been officially adopted, but by way of comparison with the standard rifle in use since the early part of World War II, the semi-automatic M-1, which weighs $9\frac{3}{4}$ pounds and fires a clip of eight cartridges, the new rifle weighs only $8\frac{1}{4}$ pounds and can fire a clip of 20 cartridges with a single press of the trigger. In target contests, the newer rifle has poured out fire at twice the rate of the M-1.

Another significant development in the modern trend has been our recoilless rifles. Taking the recoil out of weapons of heavy firepower has had the effect of putting a portable artillery piece in the hands of our troops. With the recoil eliminated, the size of the mount necessary to support the weapon has been considerably decreased.

With artillery as with small arms our efforts toward improvement have been in the direction of greater firepower, with additional emphasis on greater accuracy and greater mobility.

In line with these same objectives every phase of design in our tank and automotive equipment has received the strongest emphasis. Insofar as tanks are concerned, the lighter, more maneuverable types, characterized by great striking power, have long been favored over the heavy cumbersome types which are subject to bogging down or stalling on difficult terrain. I know of no foreseeable conditions which might change our thinking in this respect, and I believe the trend will continue.

One interesting new development in armored vehicles is our new personnel carrier. This vehicle is designed to take the infantrymen into the front lines along with the tanks, and is armored to give them protection from small arms fire and shell fragments. It will negotiate about the same terrain as the tanks, and therefore can put the Infantry with the spearhead elements. On improved roads it will travel at a sustained speed of over 35 miles per hour, it can turn in its own length, and can climb or descend slopes of 60%.

Two of the most significant new developments in our automotive equipment have been the waterproofing and standardization of our vehicles. Some of our vehicles were equipped with fording kits in World War II, but the design and employment of these devices have been so improved as to greatly extend the areas in which our vehicles can operate without kits. Our M-34 two and one-half ton cargo truck, for example, can cross a stream as deep as seven feet without benefit of a

bridge. It can likewise be driven off a landing barge into surf and go into immediate action under its own power.

During World War II, 6 different tank engines were used for the same tank. Today, 11 different vehicles use the same engine. The old engines had 5000 non-interchangeable parts. Our new engines have 2000 parts with less than 800 of the non-interchangeable category. Of the high mortality parts, all are interchangeable in the new engines.

Of 28 separate types of trucks making up the basic fleet during the last war, only seven standardized vehicles now serve the Army's tactical transportation requirements. Instead of 18 engines, 19 transmissions, 21 front axles, 16 rear axles, and 13 tire sizes, the parts inventory now includes only 7 types of each major component.

The whole standardization program is designed to effect savings in many ways: (1) through cutting unit costs by mass production methods; (2) through reducing inventories of spare parts; (3) through reducing the number of people required in maintenance and supply operations; and (4) through eliminating much training time needed to train mechanics for repair and maintenance.

Our requirements for all these tools of war are characterized by one simple term—*superior ordnance*. Our engineers working with the engineering staffs of our industrial partners never lose sight of the need for building into our Ordnance the very important elements of ruggedness, reliability and dependability, which means this *superior ordnance*. Consider, if you will, the enemy casualties in Korea . . . almost unbelievable in number. That, it seems to me, is conclusive of the difference between hordes of men inadequately armed, and our own numerically inferior forces, staunchly courageous, thoroughly trained, superbly led, and equipped with *superior ordnance* of greater firepower. *Superior ordnance* gives our troops an advantage on the battlefield . . . and it must never be otherwise.

We in the Ordnance Corps are pledged to this continuous task of producing superior fighting tools that shoot with greater power and which can be shot with greater accuracy, so that, in any conflict into which our country is drawn, our fighting men may roll on confidently, to victory.

Salt Dampening Problems Solved.—The age old problem of salt's dampening and caking in humid weather has finally been alleviated by the makers of Diamond Crystal Weather-pruf Salt, a product of General Foods. Technicians and scientists achieved this after more than 20 years of experimentation by adding calcium silicate to the pure salt. The addition of this chemical filler makes a truly moisture resistant product.

Because calcium silicate absorbs moisture at a much lower relative humidity than the salt, a great percentage of the moisture which would normally be taken up by the salt is absorbed by the chemical, leaving the salt dry and free-flowing. This chemical cannot, under every condition, absorb all the moisture before it has a chance to act upon the salt. However, the moisture which might get through will combine with the salt to form a brine and the calcium silicate will, in turn, absorb most of this brine, leaving the remaining salt free-flowing.

Calcium silicate is insoluble in water and nontoxic. Its use in a food product has absolutely no harmful effects as attested to by the fact that iodized Weather-pruf salt has been granted the American Medical Association Seal of Approval.

A one-man helicopter under development by Army Ordnance Corps weighs about 300 pounds, can be folded into a 5 × 5 × 14 foot container for aerial drops. Designed for air evacuation, supply and observation duties, the copter has top speed of 80 mph., carries fuel supply for 90-minute flights. Power is supplied by two sixteen pound pulse jet engines on the rotor blades. Engines burn gasoline, kerosene, or diesel oil, have only one moving part which can be replaced in a few minutes.

A new bore-hole camera under development by the Army Corps of Engineers can take 360 degree photographs of a 3-inch bore hole, can be used in either dry or water-filled holes. Cylindrical in shape, the camera uses a conical mirror to produce an image of a 360 degree band of the bore hole which is photographed on 16 mm. motion picture film. Pictures are projected on a conical mirror enclosed by a cylindrical diffusion screen. The camera is expected to make a vital contribution in solving foundation problems in construction of concrete structures, such as dams.

Thermal indicators made of paper have been developed by the Army Quartermaster Corps, are capable of instant temperature readings from 115 to 500 degrees F. The thermometer consists of white pigment coating on black paper; coating can be designed to melt at any definite temperature when the white pigment melts into the paper base, leaving a black background. Temperature indicators based on color changes have been used industrially for several years, but are not suitable for use by color blind persons; the black and white indicators have no such drawbacks. Materials used are readily available, and commercial production should bring cost of such thermometers down to a few cents each.

SOME STUDIES OF THE IMPACT OF VEE WEDGES ON A WATER SURFACE

BY

R. L. BISPLINGHOFF[1] AND C. S. DOHERTY[1]

SUMMARY

A brief resumé is given of the background and present status of the two-dimensional vee-wedge theory. The fundamental assumptions are reviewed, and the problem, including buoyancy forces, is formulated with arbitrary amounts of wing lift. The unsteady state force is derived, using the flow pattern about an expanding prism. A formula for the shape of the free-water surface is derived, based upon Wagner's assumption and using the flow about an expanding prism. Two-dimensional experiments are described in which accelerations were measured, and high-speed photographs of the piled-up water were taken. Experimental and theoretical results are compared.

1. INTRODUCTION

Von Karman (1)[2] made the first calculations of the load factors on seaplane hulls under the assumption that during impact the initial momentum of the dropping hull is imparted to the momentum of an apparent mass of water. The apparent mass was taken to be that associated with a flat plate, and two-dimensional flow in planes normal to the keel was assumed.

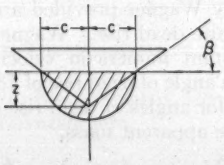

FIG. 1. Vee wedge and apparent mass assumed by von Karman.

Figure 1 illustrates a cross-sectional view of the wedge and its associated apparent mass.

Von Karman took the apparent mass per unit length as the volume shown by the cross-hatched area in Fig. 1.

$$m = \frac{\pi \rho c^2}{2} = \cot^2 \beta \frac{\pi \rho}{2} z^2 \tag{1}$$

where ρ is the mass density of water.

Calculations based on von Karman apparent mass formed the basis for early work in seaplane impact loads. The most significant contri-

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

bution to the two-dimensional problem subsequent to von Karman has been made by Wagner (2). Wagner reasoned that the formation of spray produced a piling up of water adjacent to the float and thereby increased the wetted width and apparent mass. By integrating the theoretical velocity distribution in the flow around a flat plate, Wagner computed the rise of each particle of water at every instant subsequent to the initial impact. This resulted in a water surface as shown by Fig. 2. On a basis of this result, Wagner defined the apparent mass

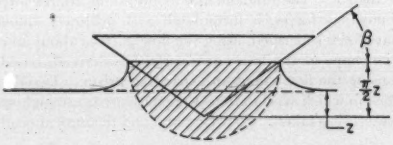


FIG. 2. Piled-up water and apparent mass computed by Wagner.

as a semicylinder with diameter $\pi/2$ times the wetted width associated with the undisturbed water surface.

$$m = \frac{\pi^2}{4}\left(\frac{\pi\rho}{2}c^2\right) = \frac{\pi^2}{4}\cot^2\beta\left(\frac{\pi\rho}{2}z^2\right). \tag{2}$$

Another contribution by Wagner provided a correction to the virtual mass for the effect of finite dead rise. Wagner made one approximate solution based on constant immersion velocity of the flow about a triangular prism with an angle of dead rise of 18°. This result, together with the known results for angles of dead rise of 0° and 90°, led to the empirical relation for the apparent mass,

$$m = \left(\frac{\pi}{2\beta} - 1\right)^2 \tan^2\beta\left(\frac{\pi\rho}{2}c^2\right) = \left(\frac{\pi}{2\beta} - 1\right)^2 \frac{\pi\rho}{2}z^2. \tag{3}$$

This expression for the apparent mass was also derived by Sydow (3) and is referred to in the present paper as the Wagner-Sydow apparent mass.

Kreps (4) proposed, after a study of experimental data, the formula for virtual mass given by

$$m = \frac{\pi^2}{4}\left(1 - \frac{\beta}{\pi}\right)\left(\frac{\pi\rho}{2}c^2\right) = \frac{\pi^2}{4}\cot^2\beta\left(1 - \frac{\beta}{\pi}\right)\left(\frac{\pi\rho}{2}z^2\right). \tag{4}$$

After studying data obtained from planing experiments, Mayo (5) inserted an empirically determined correction constant in Eq. 3, as follows:

$$m = 0.82\left(\frac{\pi}{2\beta} - 1\right)^2 \tan^2\beta\left(\frac{\pi\rho}{2}c^2\right) = 0.82\left(\frac{\pi}{2\beta} - 1\right)^2\left(\frac{\pi\rho}{2}z^2\right). \tag{5}$$

There have been few reliable experimental checks of the theories described above. In most cases, their verification has been based upon three-dimensional experiments which were not well suited for checking the fundamental two-dimensional aspects of the problem.

The purpose of the present work has been to check the existing theories by two-dimensional experiments and to extend these theories.

2. THEORY

A. *The Differential Equation*

The water surface offers resistance to the entering wedge by forces arising from two principal sources: (1) time rate of change of momentum of the fluid; and (2) buoyancy.

Assuming that there is a constant wing lift, L, of arbitrary magnitude, the differential equation of vertical motion of the two-dimensional wedge problem is,

$$M\ddot{z} - f_u - f_b = W - L = Ma_0 \tag{6}$$

where,

M = mass per unit length of the wedge.
f_u = unsteady state force resulting from the time rate of change of momentum of the fluid.
f_b = buoyancy force.
W = weight per unit length of wedge.
L = lift force per unit length of wedge.
$a_0 = \left(1 - \frac{L}{W}\right)g$ = effective acceleration of gravity acting on wedge.

The case of partial wing lift has previously been considered by Benscoter (6), and his notation is followed here.

B. *The Unsteady-State Force*

The problem to be considered in the calculation of the unsteady-state force, f_u, is the determination of the two-dimensional unsteady-flow pattern in the vicinity of a vee wedge entering the surface of a fluid. The boundary conditions must be specified in three different regions. At the free surface, the normal velocity of the fluid is the same as the velocity of the surface profile. At the wedge, the velocity of the fluid is equal to the instantaneous velocity of the wedge normal to its surface. At infinity in the fluid, the velocity is zero.

The unsteady-state force, f_u, can be defined in terms of the apparent mass, m, as follows:

$$f_u = -m\ddot{z} - \dot{m}\dot{z}. \tag{7}$$

The apparent mass, m, is related to the total kinetic energy in the fluid disturbed by the entering wedge (7), as follows:

$$T = \tfrac{1}{2}m\dot{z}^2 = -\frac{\rho}{2}\int_{(s)} \phi \frac{\partial \phi}{\partial n}\, ds, \tag{8}$$

where ϕ is the velocity potential and $\frac{\partial \phi}{\partial n}$ is the velocity of the fluid normal to the bounding area (s). The integration is to be taken over the area (s) which constitutes the area surrounding the total volume of fluid.

The line integral in Eq. 8 can be divided into three parts,

$$T = -\frac{\rho}{2}\int_{(s_1)} \phi \frac{\partial \phi}{\partial n} ds - \frac{\rho}{2}\int_{(s_2)} \phi \frac{\partial \phi}{\partial n} ds - \frac{\rho}{2}\int_{(s_3)} \phi \frac{\partial \phi}{\partial n} ds, \qquad (9)$$

where (s_1) is the boundary between the fluid and the wedge, (s_2) is the free surface of the fluid extending to infinity, and (s_3) is a boundary area in the fluid at infinity.

The integral over (s_3) vanishes since the integration is carried out at an infinite distance from the disturbance (7), and the kinetic energy becomes,

$$T = -\frac{\rho}{2}\int_{(s_1)(s_2)} \phi \frac{\partial \phi}{\partial n} ds. \qquad (10)$$

Equation 10 states that the velocity potential over the wetted surface of the body, (s_1), and over the free surface, (s_2), must be computed in order to compute the kinetic energy. The latter requires that the shape of the deformed surface and the properties of the flow in the vicinity of the free surface be known. This problem has not been solved, and it is usually assumed (2) that the free surface is a surface of zero potential. In this case, the integration over (s_2) is zero and the kinetic energy becomes,

$$T = -\frac{\rho}{2}\int_{(s_1)} \phi \frac{\partial \phi}{\partial n} ds. \qquad (11)$$

With this assumption, the wedge can be treated as though it were completely immersed in the fluid as shown by Fig. 3, and moving at a varying velocity, V. The kinetic energy of the immersed wedge is

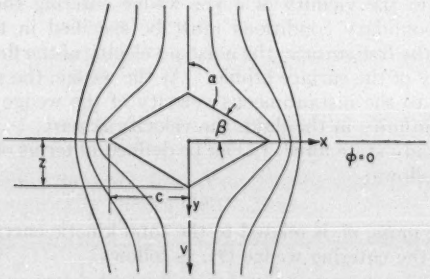


FIG. 3. Geometry of immersed wedge.

twice the kinetic energy, T.

$$2T = -\frac{\rho}{2}\int_{2s_1} \phi \frac{\partial \phi}{\partial n}\, ds, \tag{12}$$

where the integration is taken over the total boundary of the wedge.

The integral in Eq. 13 has been evaluated for the wedge case by Wagner (2), Lewis (8), and Monaghan (9). A brief statement is made here of an evaluation of Eq. 12, using a scheme suggested by Lamb (10) and applied to lens-shaped objects by Shiffman and Spencer (11).

Introducing into Eq. 12 the boundary condition,

$$\frac{\partial \phi}{\partial n} = \sin \alpha = V \frac{\partial y}{\partial n} \tag{13}$$

and applying Green's formula for a periphractic region (10),

$$2T = -\frac{\rho}{2} V \int_{(2s_1)} y \frac{\partial \phi}{\partial n}\, ds - \frac{\rho}{2} V \int_{\infty} \left(y \frac{\partial \phi}{\partial n} - \phi \frac{\partial y}{\partial n} \right) ds, \tag{14}$$

where the integral over infinity denotes an integration over the surface of the fluid at infinity.

Integrating Eq. 14 and observing that the effect of a disturbance at a great distance can be represented by a suitably selected dipole:

$$2T = -\frac{\rho V^2}{2} A + \rho V \pi a, \tag{15}$$

where A is the cross-sectional area of the wedge and a is the dipole strength.

The strength of the required dipole for a wedge of dead-rise angle, β, and width, c, can be shown to be,

$$a = Vc^2 \left(\tfrac{1}{2} - \frac{\beta}{\pi} \right) \left\{ \frac{\sqrt{\pi}}{\Gamma\left(\tfrac{1}{2} + \frac{\beta}{\pi} \right) \Gamma\left(1 - \frac{\beta}{\pi} \right) \cos \beta} \right\}^2. \tag{16}$$

Combining Eqs. 15 and 16, the apparent mass m is deduced as,

$$m = K_1 \left(\frac{\pi \rho}{2} c^2 \right) = K_1 \cot^2 \beta \left(\frac{\pi \rho}{2} z^2 \right), \tag{17}$$

where:

$$K_1 = \frac{2 \tan \beta}{\pi} \left\{ \frac{\pi^2 \left(\tfrac{1}{2} - \frac{\beta}{\pi} \right)}{\sin \beta \cos \beta \Gamma^2 \left(1 - \frac{\beta}{\pi} \right) \Gamma^2 \left(\tfrac{1}{2} + \frac{\beta}{\pi} \right)} \right\}. \tag{18}$$

The constant K_1 serves as a dead-rise correction factor to the apparent mass, $m = \frac{\pi \rho}{2} c^2$, given by von Karman, Eq. 1.

C. The Buoyancy Force

The buoyancy force can be computed by multiplying the volume of the displaced fluid by the fluid density. This is assumed to be given by,

$$f_b = -C_b(\beta)z^2 \tag{19}$$

where,

$$C_b = \frac{\rho g}{\tan \beta}.$$

D. The Piled-Up Water

In (*B*) and (*C*) the unsteady-state and buoyancy forces are computed on the assumption that the free-water surface is defined by the condition $\phi = 0$ and is collinear with the x axis, as shown by Fig. 3. Since, in the actual case, there is a piling up of water in the vicinity of the wedge, some corrections must be made.

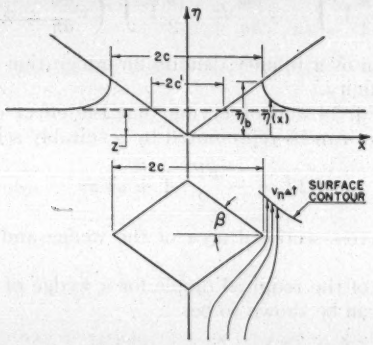


FIG. 4. Development of surface contour.

To a first approximation, the contour of the free-water surface can be computed by integrating over time the velocity of the water particles at the line of zero potential. This assumption was made by Wagner.

Figure 4 illustrates how the vertical velocity of the water particles is assumed to form a surface contour after a time Δt has elapsed subsequent to keel entry. At any point $x > c$, the rise of the water is given by,

$$\eta(x) = \int_0^t V_n \, dt, \tag{20}$$

where V_n is the velocity at the zero potential line relative to the prism.

For the case of flow about a prism, it can be shown that,

$$V_n = V\left(1 - \frac{c^2}{x^2}\right)^{\beta/\pi - \frac{1}{2}} \tag{21}$$

and the equation of the water surface becomes,

$$\eta(x) = V \int_0^t \left(1 - \frac{c^2}{x^2}\right)^{\beta/\pi - \frac{1}{2}} dt. \tag{22}$$

The semi-width, c, increases with time, and following Wagner, it is convenient to write Eq. 22 as follows,

$$\eta(x) = \int_0^{c \leq x} \left(1 - \frac{c^2}{x^2}\right)^{\beta/\pi - \frac{1}{2}} \mu(c)\, dc, \tag{23}$$

where

$$\mu(c) = V \frac{dt}{dc}.$$

An integral equation may be formed from Eq. 23 from which $\mu(c)$ can be computed. For a vee wedge,

$$c \tan \beta = \int_0^c \left(1 - \frac{\xi^2}{c^2}\right)^{\beta/\pi - \frac{1}{2}} u(\xi)\, d\xi, \tag{24}$$

where the dummy variable of integration, ξ, has been introduced.

Solution of Eq. 24 yields,

$$\mu(c) = \frac{2\beta}{\pi} K, \tag{25}$$

where

$$K = \frac{\sqrt{\pi}}{\Gamma\left(\frac{1}{2} + \frac{\beta}{\pi}\right) \Gamma\left(1 - \frac{\beta}{\pi}\right) \cos \beta}.$$

From this result, a relationship between the actual semi-wetted width, c, and the semi-width, c' (cf. Fig. 4), can be deduced,

$$c/c' = \frac{\pi \tan \beta}{2K\beta}. \tag{26}$$

Combining Eqs. 23 and 25, and applying the binomial theorem, the shape of the free-water surface becomes

$$\eta(x) = \frac{2K\beta c}{\pi}\left\{1 + \frac{\left(\frac{1}{2} - \frac{\beta}{\pi}\right)}{3}\frac{c^2}{x^2} + \frac{\left(\frac{1}{2} - \frac{\beta}{\pi}\right)\left(\frac{3}{2} - \frac{\beta}{\pi}\right)}{10}\frac{c^4}{x^4} + \frac{\left(\frac{1}{2} - \frac{\beta}{\pi}\right)\left(\frac{3}{2} - \frac{\beta}{\pi}\right)\left(\frac{5}{2} - \frac{\beta}{\pi}\right)}{42}\frac{c^6}{x^6} + \frac{\left(\frac{1}{2} - \frac{\beta}{\pi}\right)\left(\frac{3}{2} - \frac{\beta}{\pi}\right)\left(\frac{5}{2} - \frac{\beta}{\pi}\right)\left(\frac{7}{2} - \frac{\beta}{\pi}\right)}{216}\frac{c^8}{x^8} + \cdots\right\}. \tag{27}$$

When $\beta = 0$, Eq. 27 reduces to Wagner's result,

$$\eta(x) = \frac{2\beta}{\pi} x \sin^{-1} \frac{c}{x}. \tag{28}$$

E. Solution of the Differential Equation

From Eqs. 6, 7 and 19, we have for the differential equation of motion,

$$(M + m)\ddot{z} + \dot{m}\dot{z} + \frac{C_b}{\epsilon} m = Ma_0, \tag{29}$$

where

$$m = \epsilon z^2 = \frac{\rho\pi^3}{8\beta^2}\left[1 - \frac{2}{\pi}\left(\beta + \frac{\tan\beta}{K^2}\right)\right] z^2$$

and

$$C_b = \frac{\rho g}{\tan\beta}.$$

Equation 29 may be rewritten as,

$$(1 + \mu)\ddot{z} + \dot{\mu}\dot{z} + \gamma\mu = a_0, \tag{30}$$

where

$$\mu = \frac{m}{M}$$

$$\gamma = \frac{C_b}{\epsilon}.$$

Equation 30 is a non-linear differential equation of the second order in the independent variable, t, and dependent variable, z. The solution can be expressed in closed form, as follows:

$$\ddot{z} = \frac{1}{(1 + \mu)^3}\left\{a_0 - 2\left(\frac{\dot{z}_0^2}{z} + a_0 + \frac{\gamma}{2}\right)\mu - \tfrac{1}{3}(2\gamma + a_0)\mu^2 - \tfrac{1}{3}\gamma\mu^3\right\}, \tag{31}$$

where the independent variable is z, the displacement of the keel, and the dependent variable is $\ddot{z}$, the acceleration.

When γ and a_0 are put equal to zero, Eq. 31 reduces to,

$$\ddot{z} = -\frac{2\mu\dot{z}_0^2}{z(1 + \mu)^3}$$

which is the result given by von Karman (1).

When γ is put equal to zero and a_0 is put equal to g, Eq. 31 reduces to,

$$\ddot{z} = -\frac{2\mu\dot{z}_0^2}{z(1 + \mu)^3} + \frac{g(3 - 6\mu - \mu^2)}{3(1 + \mu)^3},$$

which is the result given by Benscoter (6) for the case of no wing lift.

3. EXPERIMENTAL RESULTS

A. Photographic Study of Piled-Up Water

Vee wedges were dropped vertically into a tank, and the shape of the free-water surface photographed by means of a high-speed motion-picture camera. The experimental arrangement used in these tests is shown by the photograph in Fig. 5.

The tank was rectangular and constructed of wood with a glass viewing window in the front side through which photographs were taken.

Four model wedges, with dead-rise angles of 10°, 20°, 30°, and 40° were photographed. They were of hollow wood construction and were painted to give a smooth, white surface.

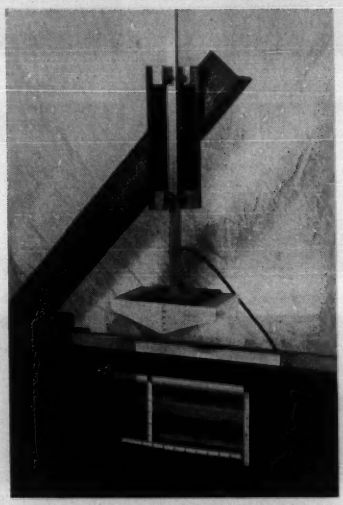
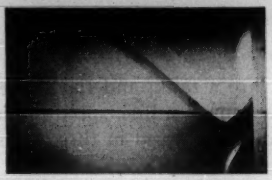


FIG. 5. Drop mechanism model and tank.

An Eastman High-Speed Movie Camera—Type 3 with a speed range of 1000 to 3000 frames per second, using 16-mm. film, was used for all tests. The $f/2.7$ coated lens had a 2.5-in. focal length. For the tests, Super XX film was used with a lens aperture of $f/4$ and a camera speed of 1500 frames per second. The lighting consisted of four photo spots, 12 in. from the model.

A typical photographic result is shown by Fig. 6. Several frames selected from the 40° wedge results are shown. It can be seen that the shape of the free surface may be determined from enlarged photographs.



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6.

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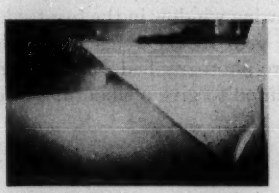

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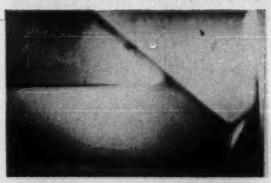

3.

8.

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9.

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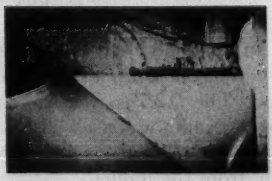

10.

FIG. 6. Typical high-speed photographs of piled-up water for 40° vee wedge.

B. Experimental Acceleration-Time Histories of Vee Wedges

The acceleration-time histories during drop tests of the 10°, 20°, 30°, 40°, and 50° vee wedges, shown by Fig. 7, were obtained experimentally. The dropping mechanism and tanks, shown by Fig. 5, were used. Accelerations were measured by a strain-gage type accelerometer, and the record was traced on a recording oscillograph. Several drops were made with each wedge, and the results for each wedge were averaged to give the final results. The separate results compared very closely so that smooth averaged curves were obtained.

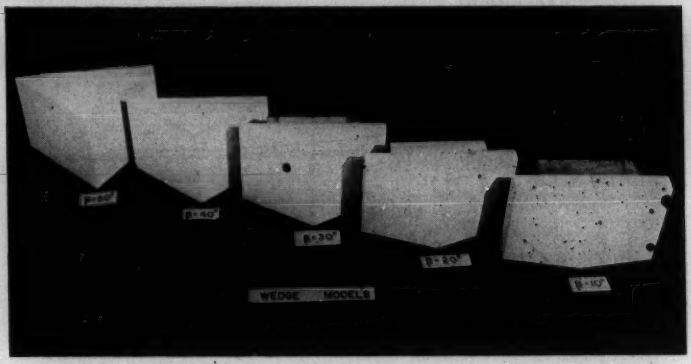

FIG. 7. Wedges used in the measurement of acceleration-time histories.

Two accelerometers were used. A ±50 g Statham accelerometer with a natural frequency of 670 c.p.s. was used for the 10° and 20° wedges, and a ±25 g Statham accelerometer with a natural frequency of 350 c.p.s. for the 30°, 40°, and 50° wedges. The accelerometer was rigidly attached to the under side of the metal cover plate at the base of the square metal rod and extended into a cavity in the wedge.

A Consolidated amplifier was used which had a carrier frequency of 3000 cycles per second and an attenuation range from 1 to 1000. The signal was recorded by a Miller oscillograph with a galvanometer natural frequency of 370 c.p.s.

4. COMPARISON BETWEEN THEORY AND EXPERIMENT

A. Piled-Up Water and Wetted Width

The shape of the free-water surface determined by experiment, as described in Section 3, is compared with the theoretical shape given by Wagner, Eq. 28, and the shape derived for the expanding prism case, Eq. 27. Figure 8 illustrates a comparison between experiment and theory for dead-rise angles of 10°, 20°, 30°, and 40°, each at a single depth of immersion.

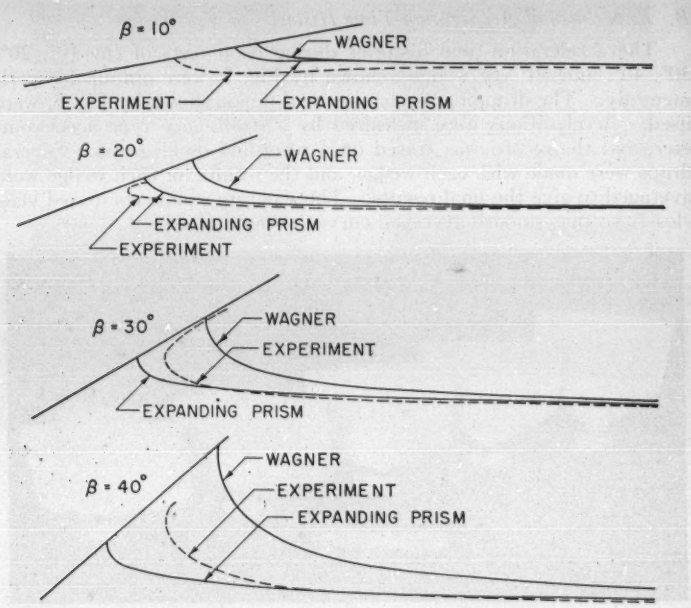

FIG. 8. Piled-up water—comparison of experiment and theory.

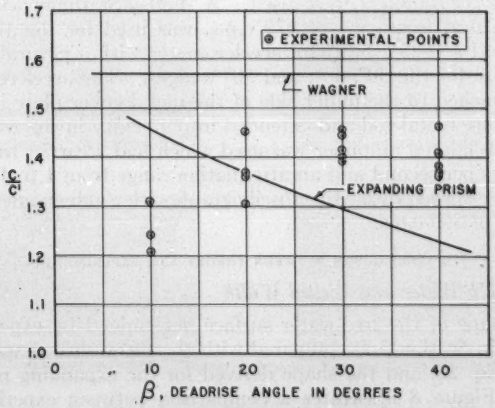

FIG. 9. Comparison of the ratio of actual width to the wetted width associated with the free-water surface.

Figure 9 illustrates a comparison between experiment and theory of the ratio between the actual semi-wetted width, c, and the semi-wetted width associated with the free-water surface, c' (cf. Fig. 4).

In general, Figs. 8 and 9 show that the expanding prism results are somewhat closer to experiment than the Wagner results. The expanding prism results agree more closely with experiment for $\beta = 20°$ and $30°$ than for $\beta = 10°$ and $40°$, and are high at the low dead-rise angles and low at the high dead-rise angles. The Wagner results are consistently high for all angles of dead rise.

B. Acceleration-Time History

The acceleration-time history curves determined by experiment, as described in Section 3, are compared with the theoretical results derived in Section 2.

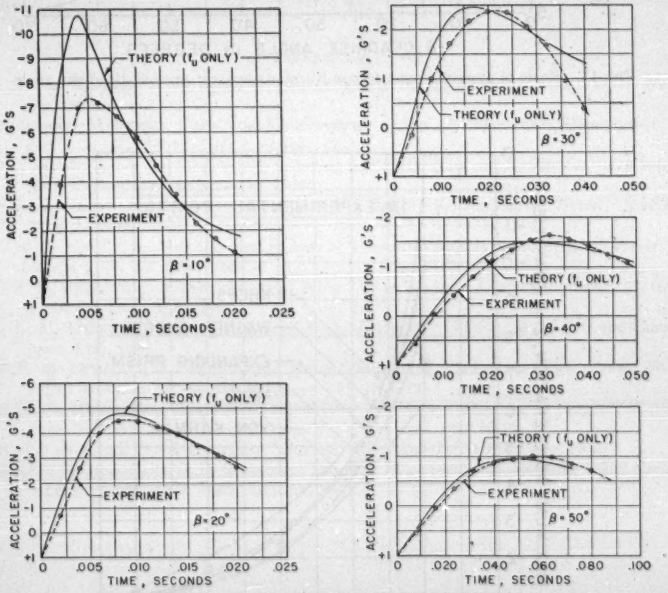

FIG. 10. Acceleration-time history—comparison of experiment and theory for 5-in. drops.

Figure 10 illustrates the comparison for 5-in. drops of the 10°, 20°, 30°, 40°, and 50° wedges. It can be seen that the agreement at 10° is not as good as at the higher dead-rise angles. In general, the trend in agreement, shown by Fig. 10, is comparable to the trends already illustrated for piled-up water.

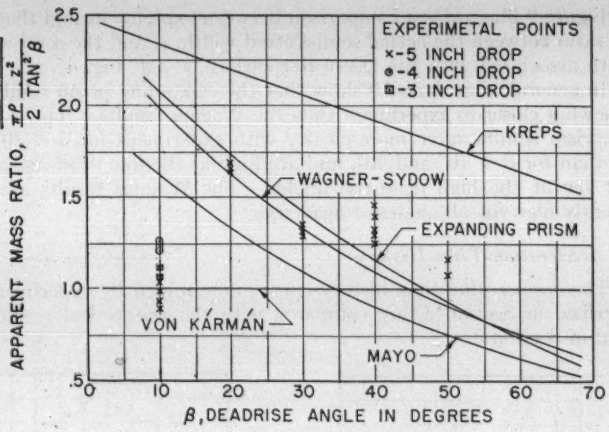

FIG. 11. Ratio of apparent mass to von Karman apparent mass *vs.* dead-rise angle.

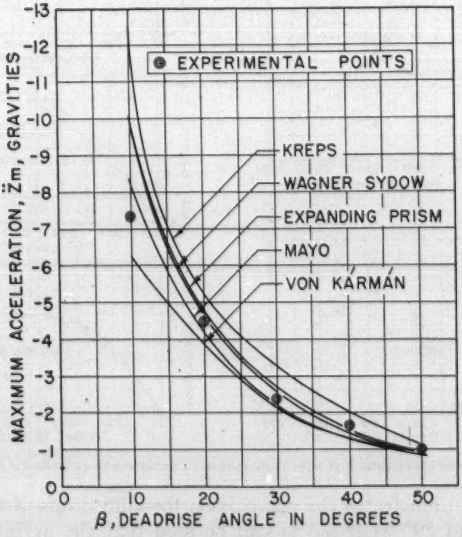

FIG. 12. Variation of maximum acceleration with dead-rise angle.

Figure 11 compares the apparent mass terms according to expanding prism theory, Wagner-Sydow, Kreps, Mayo, and von Karman, with the apparent mass computed from the peak values of the experimental acceleration-time history curves. The ordinate of Fig. 11 is expressed as a non-dimensional ratio of the apparent mass to the von Karman apparent mass. Figure 11 illustrates that the expanding prism, Wagner-Sydow and Mayo theories agree best with experimental results. Agreement between theory and experiment seems to be best at $\beta = 20°$ to $30°$ with poorer agreement at low and high dead-rise angles. The complete lack of agreement between experiment and theory at $\beta = 10°$ is again clearly shown by Fig. 11.

Figure 12 compares experiment with the five theories for the variation of maximum acceleration with dead rise. Again, the agreement between experiment and the Mayo, expanding prism, and Wagner-Sydow theories is superior, but the trend indicated by all theories is in good agreement with experimental results.

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Lightweight Tripod for Artillery.—Improved field artillery fire accuracy is now possible through the use of a lightweight tripod recently tested at Ft. Belvoir's Engineer Research and Development Laboratories.

The tripod enables combat survey parties to place and plumb ranging poles rapidly, and then take cover while observations are made. Because of the speed and simplicity of handling, the tripod is also suitable for artic survey operations.

The tripod is constructed principally of aluminum, weighs 4¼ pounds and is 42 inches long. A star-shaped head holds the three legs together. The legs have foot pieces of stainless steel points shaped to provide an angular spur when the legs are placed at normal slope. The sliding plumb bar attached to the tripod head pivots around the tripod bolt. The plumb bar is rigidly held in the desired position by the tripod bolt, and is designed to provide radial and lateral movement for plumbing the ranging pole over the desired point.

Rigorous field tests were undertaken by ERDL engineers. The tests proved that the tripod can withstand winds up to 40 miles an hour without appreciable loss of accuracy for pointings on the ranging pole. The average time for setting up the tripod and ranging pole is less than one minute. The tripod is sufficiently sturdy to withstand air drop delivery and handling under field conditions.

The tripod is now being given final evaluation tests by Army Field Forces service test agencies before being standardized by the Corps of Engineers.

New Chemical Feed Packaged Unit.—A new chemical feed packaged unit, which delivers liquids in desired amounts under pressure, has been announced by The Bird-Archer Company, of Philadelphia. This unit is ideally suited for feeding boiler water treatment as well as delivering chemicals and other fluids for processing.

This self-contained, extra heavy Baco unit offers high pressure controlled feed at low cost. The chemical reservoir tank is of sturdy welded steel construction, available in 50 or 100 gallon capacity. The chemical proportioning pump can be designed for various rates of feed at different pressures. A specially designed motor-driven agitator assures completely mixed fluids at all times. A stainless steel strainer is provided between the suction side of the pump and the tank. The pump is mounted below the tank to minimize air binding and to maintain a positive suction head.

A duplex-pump model with divided tank is also available. Both types of units are supplied complete with all necessary piping and are ready for connection.

Ocean shipment of loaded trailers is being developed by the Army Transportation Corps, to speed shipment of high priority material. First shipment of stateside loaded trailers left San Francisco in January for the Far East; trailers will be reloaded at destination with cargo for U. S. The operation will eventually eliminate much loading and unloading from one carrier to another, along with attendant storage and rehandling, provide safer movement for high value cargo.

BUCKLING OF CONTINUOUS BEAMS ON ELASTIC SUPPORTS*

BY

EDWARD SAIBEL [1]

SUMMARY

The continuous beam having elastic intermediate supports, equally spaced and of equal stiffness, is solved for the condition that they behave as rigid supports when the beam buckles under the action of an axial compressive force. The exact solution is given in closed form.

INTRODUCTION

In a recent paper, J. M. Klitchieff (1)[2] gave an approximate solution to the problem first discussed by I. G. Boobnov (2) which was to find the stiffnesses of uniform intermediate elastic supports equally spaced on a continuous beam such that they would act as though rigid and not deflect when buckling of the beam occurred under the action of an axial compressive load on the beam.

The original method of solution used by Boobnov is described by Klitchieff who gives an approximate solution by developing the deflected shape of the beam in the form of a trigonometrical series. Another method of solution is given by S. Timoshenko (3). However these various solutions may be greatly simplified and the exact solution written explicitly in closed form.

STATEMENT OF THE PROBLEM

We consider a beam of uniform cross-section which is simply supported at its ends and is supported at any number of places, equally spaced, by elastic supports of equal rigidity, Fig. 1. The beam is acted

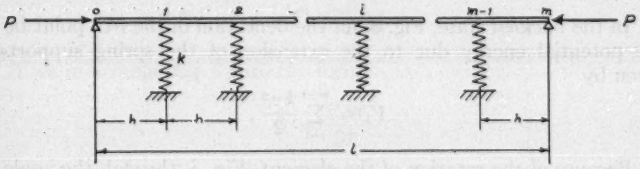

FIG. 1.

on by an axial compressive force and we wish to find what the stiffnesses or rigidities of the supports must be in order that the beam undergoes no deflection at any of the points of support.

* The research underlying this paper was partially supported by funds from a U. S. Air Force contract with Carnegie Institute of Technology.

[1] Department of Mathematics, Carnegie Institute of Technology, Pittsburgh, Pa.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

DETAILS OF THE NUMERICAL SOLUTION

When the beam buckles in the manner described above, Fig. 2, at each intermediate point of support there is an inflexion point. Conse-

FIG. 2.

quently the bending moments at these points are all equal to zero and these points of support may be treated as pin connections. The problem is thus equivalent to a set of m uniform straight beams of length h each, pin connected and supported at each of the intermediate pins by elastic supports of modulus k, that is, the reaction at each support is k times the deflection of the beam at the support.

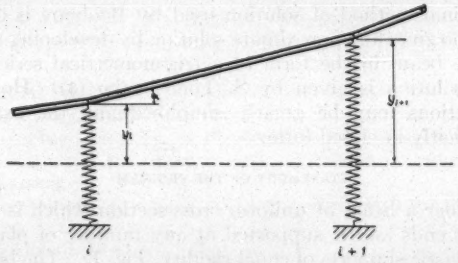

FIG. 3.

In the buckled state, Fig. 3, let the deflection of the i-th point be y_i, the potential energy due to the extension of the spring supports is given by

$$V_1 = \sum_{i=1}^{m-1} \frac{k y_i^2}{2}. \tag{1}$$

Because of the rotation of the element, Fig. 3, through the angle θ_i, the horizontal distance between points i and $i+1$ is diminished by

$$h - h \cos \theta_i \approx \frac{h}{2} \theta_i^2. \tag{2}$$

This in turn, for infinitesimal displacements, may be expressed in the form

$$\frac{1}{2h} (y_{i+1} - y_i)^2. \tag{3}$$

Consequently the loss in potential energy due to the horizontal motion of the ends of the beam toward each other is

$$V_2 = \frac{P}{2h} \sum_{i=1}^{m-1} (y_{i+1} - y_i)^2. \tag{4}$$

The potential energy of the system V may now be written

$$V = V_1 - V_2 = \frac{k}{2} \sum_{i=1}^{m-1} y_i^2 - \frac{P}{2h} \sum_{i=1}^{m-1} (y_{i+1} - y_i)^2. \tag{5}$$

Minimizing V, by making $\frac{\partial V}{\partial y_i} = 0$ for $i = 1, 2, \ldots m - 1$; leads to a system of linear homogeneous equations of the form

$$ky_i + \frac{P}{h}(y_{i+1} - y_i) - \frac{P}{h}(y_i - y_{i-1}) = 0 \tag{6}$$

or

$$y_{i+1} - (2 - \lambda)y_i + y_{i-1} = 0 \tag{7}$$

with the boundary conditions

$$y_0 = y_m = 0 \tag{8}$$

where $\lambda = kh/P$.

Equations 7 with boundary conditions given by Eqs. 8 are precisely the equations and boundary conditions of the vibrations of the stretched cord carrying a set of equal masses equally spaced (4).

The solution of this problem is given by

$$P_s = \frac{kh}{4 \sin^2 \frac{s\pi}{2m}} = \frac{kl}{4m \sin^2 \frac{s\pi}{2m}}. \quad s = 1, 2, \ldots, m - 1. \tag{9}$$

If we re-arrange Eq. 9 into the form

$$k = \frac{P_s m}{l\beta} \tag{10}$$

where

$$1/\beta = 4 \sin^2 \frac{s\pi}{2m} = 2\left(1 + \cos \frac{\pi}{m}\right) \text{ for } s = m - 1,$$

the expression will be in the precise form for comparison with the results of Timoshenko (3) and Klitchieff (1). The value of s which we use is $s = m - 1$ since we are interested in the lowest buckling load.

When the beam is buckled as shown in Fig. 2, P is the Euler critical load for a column having pinned ends and of length l/m, thus

$P = \dfrac{m^2\pi^2 EI}{l^2}$, and Eq. 10 becomes

$$k = \frac{m^3\pi^2 EI}{l^3\beta}. \tag{11}$$

Taking successive values of m, we obtain the exact value of k for any number of supports and of course duplicate the table for β, notation of Timoshenko (3), or ϕ in the notation of Klitchieff (1).

It is easily seen from Eq. 10 that as m gets large, and we put $s = m - 1$,

$$\frac{1}{\beta} = 4 \sin^2 \frac{s\pi}{2m}$$

approaches 4 as a limit.

CONCLUSION

The analogy between the original problem and that of the loaded vibrating cord suggests the use of the exact and approximate methods which have been developed for solving the latter, to solve the general case of the buckling when the supports may be located anywhere and the stiffnesses are arbitrary.

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MODERN COMPUTING MACHINES *

BY

G. TRUMAN HUNTER [1]

The popular press continues to use the term "Brains" for the modern computing machines which are the subject of my talk this evening. Actually, there are better descriptive names for these machines—one such name might be, "Information Processing Machine." That title is not as glamorous as the term "Brain," but it is more accurate.

This evening, I wish to talk principally about a class of machines now known as Digital Computing Machines. A few definitions are in order. A digital computer is defined officially by the Institute of Radio Engineers as "One in which information, numerical or otherwise, is represented by means of combinations of characters in such a way that the number of distinguishable combinations is much greater than the number of distinguishable characters. Thus, a digital computer is one which makes explicit use of a language." In contrast to this, an analog computer is defined as follows, "A physical system together with means of control for the performance of measurements (upon the system) which yield information concerning a class of mathematical problems. In an analog computer, quantities are represented without explicit use of a language." Those are official definitions.

Two definitions which are slightly less technical and somewhat more descriptive are: a digital computer is a machine which is capable of the usual arithmetic operations of add, subtract, multiply, and divide and in which a number is always represented by the integral digits of an appropriate number system. An analog computer is a machine which is capable of the usual arithmetic operations of add, subtract, multiply, and divide and in which a number is always represented, not by digits, but by such things as the linear or circular postion of an object, or an amount of electrical voltage or current.

I am not going to discuss the usual adding machine and desk calculator with which all of you are familiar because they are not capable of performing several arithmetic operations in sequence without human intervention.

Also, I am not going to discuss analog machines after the two following statements. Analog machines have developed technically about the same as digital machines. They are particularly well-suited to a few

* Lecture presented at a Joint Meeting of The Franklin Institute and the Instruments and Measurements Group of the American Institute of Electrical Engineers, January 23, 1952, in the Lecture Hall of The Franklin Institute.

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classes of problems but they are not, in general, capable of operating with an accuracy better than 0.1 per cent.

I promised to give a brief history of the development of computing machines. It will have to be brief for the historical facts alone could easily take up the whole hour. The first real prophet and thinker in the field of computing machines was an English professor of mathematics named Charles Babbage. His ideas for computing machines, formulated over 100 years ago, would be considered quite modern today even though they included nothing in electronics or nuclear terms. His machine was to be controlled through the use of punched cards

FIG. 1. IBM-HARVARD Automatic Sequence Controlled Calculator.

and mechanical plungers which could "feel" the holes in the cards. This same type of operation is used in some office equipment today. His machine was to store 50,000 decimal digits which is more than any machine in operation today can hold without the use of punched paper or magnetic tapes.

One feature which particularly fascinates me was the ability of the machine to recognize what we today call "operator error." Babbage's machine would stop and ring a bell when it needed attention. If it was not supplied with the correct information, it would "ring a louder

bell, stop, and display a notice, 'wrong number card.'" When mechanical engineering ability advanced to the accuracy that it could build Babbage's machine, a part of the design was constructed. This equipment was used to calculate the value of π to 29 places all of which were correct.

Punched card accounting machines developed during the 1920's and 1930's and the experience gained in this field led to the construction of the machine which I believe signifies the beginning of the modern computing age. This machine is called the Automatic Sequence Controlled Calculator or the Mark I. This machine was designed jointly

FIG. 2. IBM Selective Sequence Electronic Calculator.

by the International Business Machines Corporation and Harvard University, built by IBM mostly from components of standard accounting machines and given to Harvard University at the time of the dedication of the calculator in 1944. This machine is shown in Fig. 1. It can store 1656 decimal digits and has 1380 additional digits which can be preset and used as numerical constants in the calculation of a problem. This machine can perform many arithmetic operations in sequence without human intervention. It is important because it was

the first large scale digital calculator ever built and also because it stimulated the imagination and interest of the world and thus gave impetus to the desire for more and better computing machines.

The next big machine and milepost in this history is the ENIAC designed and built by the Moore School of Electrical Engineering at the University of Pennsylvania here in Philadelphia. It was completed in 1946. This machine has a digit storage capacity of 240 decimal digits plus 3744 digits of preset constants. It uses about 18,000 vacuum tubes. The ENIAC is important because it showed the great increase in operating speed which electronics could provide over mechanical computers. Since it was designed, the ENIAC has undergone quite a bit of modernization so that it could be more easily operated and changed from one problem to another. It was built specifically for solving ballistics problems but its versatility is shown by the fact that it has been used to compute the value of π to over 2000 places. In case you are interested, the 2000th digit is zero.

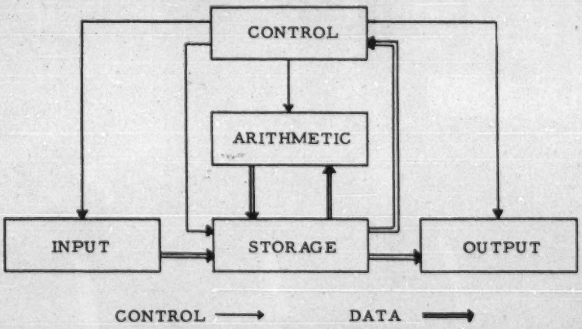

FIG. 3. Block diagram of computer.

The next big machine I shall mention is the IBM Selective Sequence Electronic Calculator, put into operation in January 1948. A picture of this machine is shown in Fig. 2. This SSEC, as it is now known, is important because it has much larger storage facilities than either of the previous machines. It stores 160 digits in vacuum tube storage, 3000 digits in relay storage, and 400,000 digits in punched tape storage. It also has fast printing output equipment which can keep up with the electronic computing speed. It can be very quickly and easily changed from one problem to a different one. The number of vacuum tubes used in this calculator is only 12,000.

These three computing machines, plus a few others, represent the starting phase in the extremely rapidly growing field of computing machines. So much for "ancient history."

When an engineer starts talking about a piece of equipment, he

usually starts with a block diagram, and I am going to do that here. A computing machine can be thought of as being composed of five components. They are shown in Fig. 3. I shall discuss each of these blocks or components briefly.

To the engineer, the input component or device may be thought of as the impedance matching device between the outside world and the operating region of the computer. It is generally some sort of an electromechanical device. Information may be entered directly into a computer by an operator who manipulates a set of keys similar to a typewriter or adding machine keyboard. Information may also be accepted from punched cards, punched paper tape (like teletype tape), from photographic films, or from magnetic tape or wire. Each of these types of input has certain advantages, and it also has some disadvantages. I have time to mention only a few of these this evening.

A single punched card may be easily changed in a file of cards used for input purposes. Also, the information which is punched into the

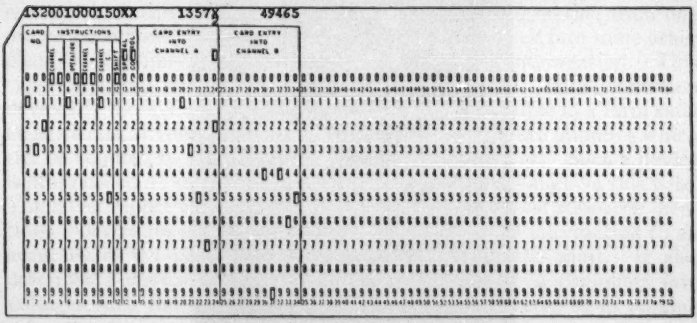

FIG. 4. IBM card for computer input.

card may also be printed on the card so that it can be easily read by a person without the use of auxiliary equipment. Punched cards at present are not moved back and forth past the reading unit without human assistance while continuous tapes may be handled in this manner. A recent IBM machine was announced with the ability to read 1000 cards per minute—a rate of 80,000 decimal digits per minute, which is getting in the order of magnitude of reading speed for magnetic tapes. Figure 4 shows a typical IBM card which is used for the input of data or instructions into a computing machine. This card contains two numbers and the instructions to add them.

Magnetic tapes can be erased and used over and over. They move at high speed, of the order of magnitude of from 2000 to 10,000 digits per second or 120,000 to 600,000 digits per minute. Magnetic tapes

can not be read without the aid of auxiliary equipment. A single item can not be changed without putting a magnetic tape into a computer. A typical magnetic tape unit is shown in Fig. 5. Briefly, there is no one perfect input device.

The next block I want to consider is the one labeled "output." The output part of a computing machine is the equipment which is used to bring information out of the computer and prepare it in some suitable form for further use. In most cases a printed answer is required. The electric typewriter which was fast enough for printing results from the Mark I is not suitable for today's high speed electronic

FIG. 5. IBM Magnetic Tape Unit.

computers. One way to get around this slow typing speed is to bring information out of the computer on magnetic tape and then have ten or twenty auxiliary pieces of equipment to process the tape and produce typewritten material.

A line printing device is a much better answer to the problem. IBM has had such a device for about 25 years. This device is capable of

printing over 9000 characters per minute and the latest model, which is in mass production, is capable of printing 18,000 characters per minute as compared to a printing speed of 900 characters per minute, which is the best that an electric typewriter can achieve.

There are rumors and reports of even faster printers. The January 1952 issue of *Fortune Magazine* reports a printing device which is said to be able to print 2000 lines a minute. Another device which uses high speed photography of cathode-ray tubes is reported by the Office of Naval Research to have a printing rate ranging from 1000 to 10,000 characters per second.

I should like to pay tribute to the engineers in this wonderful country of ours who, when given an urgent demand to produce something, usually come up with something much better than the original request.

In connection with the input-output requirements, I would like to mention two additional problems. Of particular interest to the members of the Instruments and Measurements Groups of the AIEE who are here this evening, is the idea of getting information from one piece of machinery into a computer and the result back into some other piece of machinery without having any human intervention. This type of operation requires what are known as "data-conversion devices." Sometimes the initial information is available in a form such as an electrical voltage. This must be transformed into impulses which can be counted to form the digits in a digital computer. Such a device is often called a "digitizer." Rapid progress is being made in this field. The latest report which I have from the Office of Naval Research mentions a device for converting shaft rotation to digital information to an accuracy of 0.1 per cent with negligible load on the shaft. It also describes a device for converting digital output of a computer into voltages with the same accuracy. If any one is interested in making a fortune, here is a field in which there is still room for a great deal of development.

The other aspect of this input-output situation is that all computer problems do not have the same requirements. I shall mention two kinds of problems which show a great difference in their requirements. One problem, which I call a mathematical type of problem, is that of computing auto-correlations within a set of 100 numbers. In this case, an input of 100 numbers would require thousands of calculations to arrive at a few answers. The opposite case is that of an accounting or data-handling problem which might require thousands of numbers of input, very little computing, and then thousands of numbers of output. You can easily see that these two types of problems make quite different demands on a machine. Most problems lie between these two extremes.

I have often been asked about the possibility of having a calculator

which would respond to the human voice. Such a machine might be possible, but you have to remember that different languages and even the different accents within any one language would make the design rather difficult. I don't believe that we shall see such a machine in the very near future.

Now let us consider the storage components of computing machines. First, I shall define a few terms. A *storage device* is a piece of equipment into which information can be introduced and then from which that same information may be extracted at a later time. A *word* is defined in computer terminology as a group of characters (usually digits) having a meaning and considered as a unit. A word may be either data or an instruction. An *address* is usually a number which designates a particular location in a storage device. An *instruction* is information,

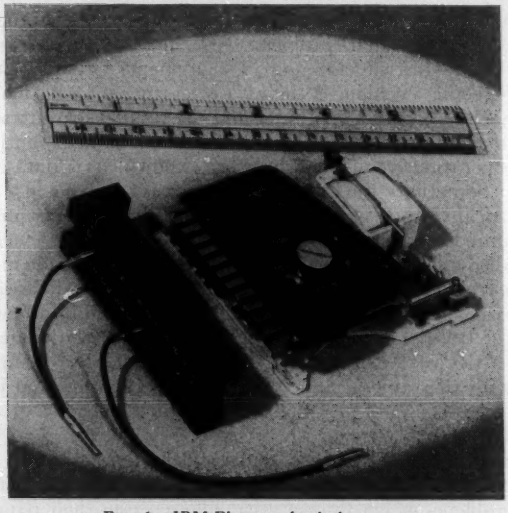

FIG. 6. IBM Electomechanical counter.

usually in numerical form, which will cause a computing machine to perform one or more operations. One or more addresses are usually included as part of the instruction.

Figure 6 shows a typical electromechanical type of storage device for storing one decimal digit. It is a ten position counter wheel used in many IBM machines. This is the equivalent of four or more electrical relays which are sometimes used as storage devices in other machines.

Figure 7 shows one of the vacuum tube and circuit assemblies out of an IBM electronic calculator. This and three other such plug-in assemblies are used to store one decimal digit. Most modern machines

use plug-in units such as these for ease of manufacture, and repair. Test problems and procedures allow most machine difficulties to be found and corrected very quickly and easily.

Another medium which may be used either for storage or for input-output type of operation is the magnetic tape. As a piece of input-output equipment it operates at relatively high speed. As a storage device, it is sometimes used as a relatively large capacity but slow speed device.

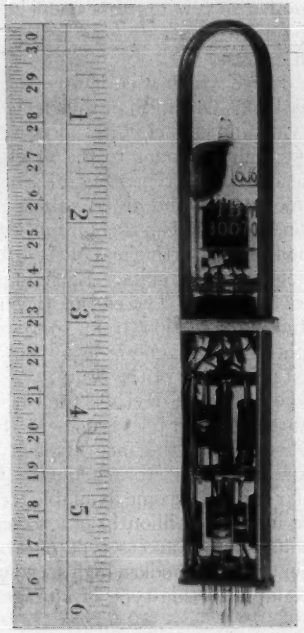

FIG. 7. IBM electronic counter unit.

At this point I had better define my time scale. In the computer field these days, if a number is not available from storage in a few millionths of a second, the storage system is considered to be relatively slow. To search a whole reel of tape will take several minutes. On the other hand, the tape is a fairly compact type of storage and it is a permanent type of storage. That is, if the power should fail for a computing machine, the information stored on tapes will not be lost.

The next obvious step is to prepare a short, wide, endless magnetic tape on a cylindrical form. Such a device is then called a magnetic drum. A drum is kept rotating at all times, while a tape is moved

only when it is called for. Information is stored on the magnetic tape or drum surfaces as small "spots" of magnetism. More than one thousand such spots may be placed on a single square inch of surface. These spots represent information. The information may be read from the surface over and over if desired, and it may be replaced by different information when that should be desired. The magnetic drum represents a very compact type of storage device and any information on the surface of the drum is available in a few thousandths of a second. The approximate number of vacuum tubes which are needed in connection with the drum type of storage varies from 1 to 10 for each 1000 decimal digits which are stored.

Another storage device which was devised several years ago is the electric or sonic delay line. One form of this device is a tube of mercury with the associated vacuum tube circuits. From a philosophical viewpoint, this type of storage is similar to the magnetic drum. A series of impulses or vibrations which represent information move from one end of the tube of mercury to the other, taking about 200 millionths of a second to move one foot. When these impulses reach the end of the tube, they are returned to the starting end of the tube almost instantaneously by means of electronic circuits. Each impulse travels around this loop over and over again. The end of the tube is also a reading position for extracting information from this storage device. In a similar manner, a spot on the magnetic drum surface passes a reading position once for each revolution of the drum.

An even faster type of storage device is the cathode-ray tube. This is similar to the picture tube in a television set. Hundreds of spots of information may be stored on the face of such a tube. The most important characteristic of this storage device is that there is no waiting for a particular spot to become available for reading. Information is thus available in a few millionths of a second. It is sometimes called an instantaneous random access type of storage. This type of storage is being used in the most modern high speed computer design and construction. An example of this type of storage device is shown in Fig. 8.

The cathode-ray tube, the delay line, the vacuum tube and some relay storage devices all have one common disadvantage. If the power should fail, any information which is stored would be lost. Because of this characteristic, these types of storage are sometimes called "volatile" or "temporary" types of storage.

There are other types of storage device being studied. Here again is a field in which there is tremendous room for improvement.

Incidentally, no one has come even close to designing a storage device which is as compact and as efficient as the storage device which every human being has. I refer to the human brain which can store thousands of pieces of information and also process them and associate them in thousands of ways. One estimate has been made that a machine

as capable as the human brain would require a skyscraper to house it, the power of Niagara Falls to run it, and the cooling ability of all the water from the falls to keep it cool.

In my discussion of these different types of storage devices, I have repeatedly used the terms "spots" or "impulses." By now it is apparent

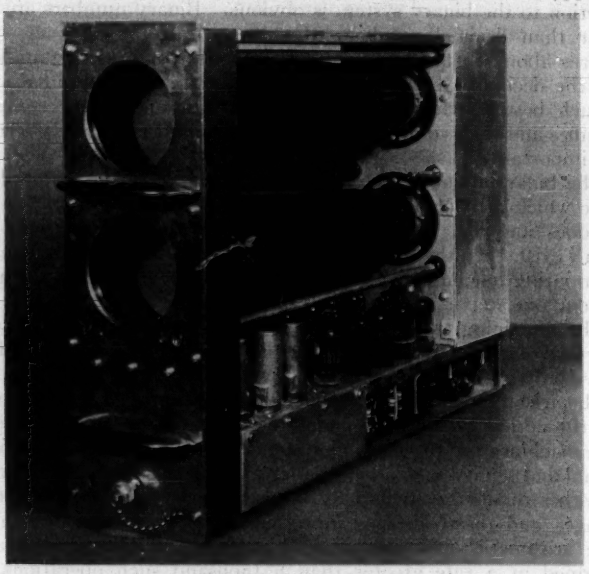

FIG. 8. IBM cathode-ray tube storage unit.

to most of you that this implies the use of a binary type of operation. In computer terminology, the word "spot," which I have been using, is usually called a binary digit or a "bit." Magnetic, vacuum tube, cathode-ray, and even relay types of storage utilize binary type of operation or arithmetic. Table I shows a comparison of numbers

TABLE I.

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
1952	11110100000

represented by the usual decimal system and by the binary number system. In the binary number system there are only two characters, the *one* and the *zero*. Every number must be made up of combinations of these two characters.

Just by looking at the date 1952 in the two number systems, one objection to the binary system is obvious. Binary numbers are much longer than decimal numbers. On the average, the binary system requires about $3\frac{1}{2}$ times as many characters to represent numbers as does the decimal system. For a manual system, the decimal system is much better. However, because of the nature of the computing machines and their components, the binary number system is becoming very important.

The binary number system is also the basis for the simple logical choice which a machine may make. A certain condition either exists or it does not exist. If it does exist, then one thing will happen. If it doesn't exist, then the other thing will happen. In this simple manner a computing machine can go through a very complex, mathematical problem, one step at a time.

The remaining two blocks in the block diagram (Fig. 3) require a great deal of explanation if all the details are to be given, so I shall have to give only the general statement of what they do.

The arithmetic unit is a combination of vacuum-tube circuits which does the actual calculations under the direction of the control block. Some machines use the decimal system, some machines use a modified decimal and binary system, and other machines use the binary system. Still other number systems may be used, each system having its advantages and disadvantages in terms of speed and equipment. A single arithmetic operation on a pair of ten digit numbers may be performed at a rate greater than a thousand such operations each second in machines which are operating today.

The control center tells the machine where to get data, what operations it is to perform and where to place the answer. The control center is only following a predetermined sequence of operations which has been stored in the computer. A sequence of operations is called a *program*. Very often the control center is instructed to choose between a pair of sequences, the choice depending upon the value of some number which has already been computed. This choice or ability to exercise judgment is one reason for using the term "brain" for a computing machine. Actually all the instructions, conditions, and both sequences of operations which may be followed must have been given to the machine.

As an example of the manner in which a machine performs a calculation, I have chosen the calculation of the square root of the number 9. As you all know the result should be the value 3. The process of obtaining the square root by a calculator requires the iterative or repeated

use of the following formula: $\left(\frac{N}{R_o} + R_o\right)\frac{1}{2} = R_n$, where N = the number whose root is desired, R_o = the old approximation to the square root, and R_n = the new (and better) approximation to the square root. As soon as a value of R_n is obtained it is compared with R_o. If the two are not the same, the value of R_n becomes the value R_o and a new R_n is calculated. This procedure is repeated until R_n equals R_o (to any required degree of accuracy). At this time the machine will stop or go on to another operation depending upon the instructions which it has been given.

One way to start the calculation is to allow the value of N to also be the value R_o. The calculation then proceeds as follows:

Step Number	Description	Calculation
1.	Calculate $\frac{N}{R_o}$	$\frac{9}{9} = 1$
2.	Add R_o to result of step No. 1	$9 + 1 = 10$
3.	Multiply $\frac{1}{2}$ times result of step No. 2	$\frac{1}{2} \times 10 = 5$
4.	Test: Are R_n and R_o the same?	Does $5 = 9$?
5.	Answer to No. 4 is no, store R_n in place of R_o	Replace 9 by 5
6.	Calculate $\frac{N}{R_o}$	$\frac{9}{5} = 1.80$
7.	Add R_o to result of step No. 6	$5 + 1.80 = 6.80$
8.	Multiply $\frac{1}{2}$ times result of step No. 7	$\frac{1}{2} \times 6.80 = 3.40$
9.	Test: Are R_n and R_o the same?	Does $3.40 = 5$?
10.	Answer to No. 9 is no, store R_n in place of R_o	Replace 5 by 3.40,

The operations are repeated finding R_n to be 3.02, 3.00, and again 3.00 (keeping only 2 decimals). On step No. 24, the answer would be yes, $R_n = R_o$, and the calculation would be complete.

It should be noted that the instructions repeat themselves in groups of five. The usual system is to have only 6 instructions instead of 25 or more for this calculation. Four are used each time, and the machine chooses one of the two remaining instructions on the fifth step, depending on the result of the comparison test. If the result is no, the machine goes back to instruction number one. If the result of the test is yes, the machine uses the sixth instruction which may be stop, go on to the next part of the problem, or some similar instruction.

To expand on this, the whole program of computation of the square root can be considered as a sub-program, which is called for by a single instruction. Wherever possible, a program is used over and over. An example of the saving of this type is as follows. Suppose that a certain sequence contains 1000 instructions. This sequence is to be used ten times. Writing the ten sequences would take 10,000 instructions, but writing ten repeat instructions and the one long sequence might take only 1002 instructions with a saving of 8998 instructions. This saving is very important from a time and preparation standpoint, as well as

from a storage viewpoint since the instructions may take up room which is needed for the data of the actual problem.

Just how complicated is the operation of programming? It is quite true that some theoretical mathematical problems require a very competent mathematician to decide the proper method of solution, but once the method of procedure is decided, the actual programming is reduced to simple logical steps of arithmetic within the rules of operation of the machine.

The instructions or rules of operation are the language of the computer. All computers have a simple vocabulary. Some of the instructions found in most computing machines are: (1) add; (2) subtract; (3) multiply; (4) divide; (5) transfer a number from one storage location to another; (6) test to see if a particular value is zero; (7) test to see if a particular value is positive; (8) test to see if a particular value is negative; (8) skip to instruction number *xxx* (or location where the instruction may be stored); (10) read a word or words into the computer; (11) read a word or words out of the computer; (12) shift a number to the right (the number of positions must be specified); (13) shift a number to the left (the number of positions must be specified).

As a result of instructions such as number 6, 7, and 8, some other instructions may be specified. Such instructions are usually called conditional instructions. If a certain condition exists, then do one thing. If the conditon does not exist, then do a different thing. If you will examine these instructions you will see that you can do any arithmetic problem, one step at a time, and that is exactly what a computing machine does.

In the example of calculating the square root of 9 I did not use a specific machine code because all machines vary slightly in their code, instructions, and rules for programming. You would have to know the particular machine in order to understand the reason for using the particular instructions.

What machines are in existence today and what are they doing? The Association for Computing Machines reports that there are about 90 companies engaged in some way in the computer business. Of the large machines now operating or under construction, all but two of them are one-of-a-kind machines. Most of the machines were built either for research studies in computer design or for particular government research installations with particular computing needs. The Eniac, Edvac, Seac, Swac, Johniac, Ordvac are the names of a few of these machines.

Of the two exceptions that I mentioned previously, one is the Univac which is being built in Philadelphia. The first of these machines has already been delivered to the Census where it is working on part of the 1950 census. I understand that two others are being tested in preparation for delivery in 1952. One feature of the Univac which makes it

different from all previous machines is its ability to handle alphabetic as well as numeric information without any special coding being required.

The other exception that I mentioned is a new calculator being mass produced by the International Business Machines Corporation for the atomic energy, guided missile, and other urgent research demands of the defense program of this country—the first machine of its speed to be put into production. They combine punched card and magnetic tape types of input; punched card, magnetic tape and high speed line printer types of output; cathode-ray tube, magnetic drum, and magnetic tape types of storage mechanisms; and they have high speed control and arithmetic circuits.

Of the smaller electronic computers, two have been mass produced in the past three years. Many hundreds of the IBM electronic calculating punches (type 604) are in use today all over the United States, most of them doing calculations in accounting installations. Over a hundred of IBM's Card Programmed Calculators are in use today, most of them doing engineering and scientific types of calculations. This CPC, as one of these latter machines is usually called, can store up to 940 digits, has an electronic arithmetic unit, and can print up to 13,350 characters per minute. The CPC is shown in Fig. 9.

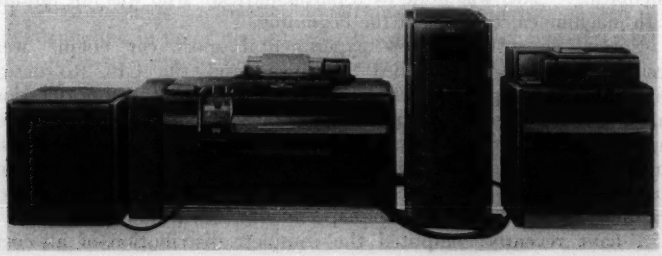

FIG. 9. IBM Card Programmed Calculator.

It is my understanding that another company has just announced the production of their first few small office-size electronic calculating punches. This machine is similar to the IBM machine (604) and it is to be produced in quantity. Several other companies are reported to be building one or a few machines with electronic circuits, magnetic drum type of storage, and typewriter or similar type of input-output device.

These computing machines will have be mass produced if they are to be given a price which industry can afford to pay. There is an additional advantage to having many machines of one kind. The results of programming and the techniques and the problem analysis

which have been done once for one installation are then available for the other installations, and this may easily result in the saving of thousands of hours of work and a corresponding saving in dollars.

Several descriptions of the problems being performed on various electronic machines have been published. Many problems which have been solved are quite routine mathematical and engineering problems. I shall mention a few of the more interesting applications which are not already in print.

One company uses a CPC to determine how to ship its products to their various destinations for the minimum cost. The CPC can solve the problem in a few hours and print the shipping instructions. This is much faster than a hand computation. This is representative of a great class of economic problems which are being considered for machines. The theorists claim that *if* they know all the factors which affect a business, then a machine can tell you exactly how to run the business. This is still somewhat in the future, however.

One company used to refer to a book of tables one half inch thick in connection with certain calculations. They now calculate the book value in 11 seconds in a CPC as they go along in their calculations.

A problem in compressor design normally taking one week of hand calculations was solved in one day including all the planning and calculating. This was done by a mathematician who was not familiar with machine calculations at the beginning.

Special cams for a new experimental sport car engine were designed on the CPC. IBM has also used the CPC to design parts of calculating machines. This of course brings up the question, can a machine design another machine? Such ideas have long been found in the science fiction magazines. We have used machine assistance along with Boolean Algebra equations to design circuits for some machines. In one case, one half an hour produced the results which originally required two weeks of experimental work.

I have recently computed the complete distribution of all costs among 51 departments of a company. A partial solution had been obtained previously in 300 hours of hand calculation. The complete and accurate distribution was calculated on a CPC in 35 minutes. A similar cost distribution was just performed for 80 departments of a company here in Philadelpha in the same length of calculating time with the same estimated saving of computing time. This type of machine calculation will soon have wide application in the field of cost accounting.

One airplane company saved an airplane by a few hours of computing. An aileron control design was changed slightly. A few hours of calculation showed that if the plane had gotten in the air, the aileron would have gone into vibration and torn itself off the plane. The plane was stopped just as it was going out for a test flight. This same

calculator predicted a strong vibration in the landing gear structure which was found the first time the airplane started to take off from its test field.

One airplane company can compute the weight and center of gravity of an airplane from 9000 separate assemblies in a little over an hour whenever they want to find out the effect of some change in design.

Whenever a new problem is to be put in the form for automatic machine calculation (which is not always the same procedure as used in hand calculations) it must be analyzed to determine the best procedure and the best machine. One good result of all the talk about machines is that many operations now being performed can be made more efficient, sometimes even without putting them on a machine. One particular wage contract which took four pages to write out, upon analysis was found to be represented in a simple equation of 10 terms. Even more important, it was found that some items in the contract contradicted themselves and disappeared from the final calculations entirely.

We are in the midst of a revolution in the way in which we are processing information. It is not sudden. You can not sign an order and a check for a million dollar machine and then suddenly be a computer, and do all your work by pushing a button.

It is most important that people interested in this particular revolution get all the facts, try to keep up with new developments as they are announced, and in particular consider not just one machine but a whole new approach to the method of processing information.

The Ferro-Resonant Flip-Flop.—A ferro-resonant flip-flop was described by Carl Isborn of the Computer Research Corporation, Hawthorne, Calif., at the recent I. R. E. convention. The individual unit consists of an inductance in series with a capacitance and a low resistance. The reactance of the inductance is non-linear and decreases with increasing current. The value of the capacitance is chosen to resonate with the inductance at some intermediate value of current. Then, as current is increased, the voltage across the circuit will increase, then *tend* to decrease until the resonant point is reached, and finally increase. By applying an a-c. signal pulse, the current corresponding to a particular voltage can be made to jump from the lower value to the higher value. Reversal of the process is achieved by suppressing the voltage across the unit and forcing it to a value below the bi-stable state.

The device lends itself to the construction of ring counters since it requires very little more power to operate a 10 position ring than a 2 position flip-flop. Another advantage of the unit is that no vacuum tubes are required.

Mercury-Vapor Detectors.—Two completely redesigned portable mercury-vapor detectors—the Type A (Electronic) and the Type B (Chemical)—for indicating concentrations of mercury which could be harmful to industrial workers, have been announced by the Special Products Division of the General Electric Company.

The new detectors, redesigned by the company's General Engineering Laboratory, are expected to be used widely by manufacturers of electrical apparatus, instruments, bulbs and glassware, fur, salt, rubber; and by the chemical, metal mining, and smelting industries. The lighter, more compact instruments, G-E engineers said, will also prove helpful to insurance companies, public health departments, and laboratories.

The Electronic instrument is designed to give an instantaneous indication of mercury vapor by resonant absorption of ultraviolet energy. It will give instantaneous readings ranging from 0.01 to 3.0 milligrams of mercury per cubic meter of air, and features greater operational stability independent of line voltage. This is possible, the engineers said, because of an additional phototube in a bridge circuit which measures the visible light, thus maintaining the bridge balance although the line voltage may vary.

Accuracy for determination with the electronic detector is within plus or minus five per cent.

The chemical-mercury-vapor detector operates on the principle that activated selenium sulphide, deposited upon a thin sheet of paper, will darken in the presence of mercury. It is designed for continuous monitoring and will indicate as little as 0.10 milligrams of mercury per cubic of air in two hours—the toxic limit for continual breathing of mercury vapor as established by the American Standards Association.

Housed in a small steel cabinet, the new chemical model has an increased sensitivity factor of approximately four. Its accuracy of determination has been increased over the earlier model by use of a thermoswitch and heater which holds the air sample constant. A blower is used to obtain a constant, positive air flow over the indicator paper, thus improving the dependability of its results.

SEPARABILITY CONDITIONS FOR THE LAPLACE AND HELMHOLTZ EQUATIONS

BY

PARRY MOON[1] AND DOMINA EBERLE SPENCER[2]

The ordinary method of solution of partial differential equations is by separation of variables, the partial differential equation in n independent variables being broken down into n ordinary differential equations. But with many coordinate systems, this process is impossible, and thus a study of separability conditions is important. Robertson considered simple separability of the Schrödinger equation, and various fragmentary investigations have been made by others. But there seems to be no reasonably comprehensive treatment of the subject.

The purpose of the present paper is to consider necessary and sufficient conditions for separability of the following equations:

(a) Schrödinger equation,

$$\nabla^2\varphi + k^2(E - V)\varphi = 0;$$

(b) Helmholtz equation,

$$\nabla^2\varphi + k^2\varphi = 0;$$

(c) Wave equation,

$$\nabla^2\varphi = \frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2};$$

(d) Damped wave equation,

$$\nabla^2\varphi = \frac{1}{c^2}\frac{\partial^2\varphi}{\partial t^2} + R\frac{\partial\varphi}{\partial t};$$

(e) Diffusion equation,

$$\nabla^2\varphi = \frac{1}{h^2}\frac{\partial\varphi}{\partial t};$$

(f) Poisson equation,

$$\nabla^2\varphi = K;$$

(g) Laplace equation,

$$\nabla^2\varphi = 0.$$

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Since the wave and diffusion equations can be reduced to the Helmholtz equation by separation of the time-term, while the Poisson equation can be reduced to the Laplace by change of variable, only three, (*a*), (*b*), (*g*), of the foregoing equations require individual treatment.

If the assumption,

$$\varphi = U^1(u^1) \cdot U^2(u^2) \ \ldots \ U^n(u^n)$$

permits the reduction of the partial differential equation to a set of n ordinary differential equations, we say that the equation is *simply separable*. Robertson's method (1),[3] which he used in obtaining conditions for simple separability of the Schrödinger equation, will be extended in this paper to the Helmholtz and Laplace equations.

A more general type of separability is also possible. If the assumption,

$$\varphi = \frac{U^1(u^1) \cdot U^2(u^2) \ \ldots \ U^n(u^n)}{R(u^1, u^2, \ \ldots \ u^n)}$$

permits separation into n ordinary differential equations, and if $R \neq$ const, the equation is said to be *R-separable*. *R*-separation of the Laplace equation has been employed by C. Neumann (2) (1862), Wangerin (3) (1875), Darboux (4) (1876), Bôcher (5) (1891), and others. A brief treatment is given by Morse and Feshbach (6). The present paper extends the Robertson method to obtain necessary and sufficient conditions for *R*-separability of the Helmholtz and Laplace equations.

1. SIMPLE SEPARABILITY OF THE HELMHOLTZ EQUATION

The Helmholtz equation, for euclidean n-space and an orthogonal coordinate system $(u^1, u^2, \ \ldots \ u^n)$, may be written

$$\frac{1}{\sqrt{g}} \sum_{i=1}^{n} \frac{\partial}{\partial u^i} \left(\frac{\sqrt{g}}{g_{ii}} \frac{\partial \varphi}{\partial u^i} \right) + (k)^2 \varphi = 0. \tag{1}$$

Since separation is never possible unless the coordinate system is an orthogonal one, we have at the outset

$$\begin{aligned} g_{ij} &= 0 \quad \text{if} \quad i \neq j, \\ g &= g_{11} g_{22} \ \ldots \ g_{nn}. \end{aligned} \tag{2}$$

Assume that the potential may be written as a product:

$$\varphi = U^1(u^1) \cdot U^2(u^2) \ \ldots \ U^n(u^n). \tag{3}$$

This assumed form is then substituted into Eq. 1, and conditions are formulated such that Eq. 3 allows separation. Substitution of Eq. 3 in (1) gives

$$\sum_{i=1}^{n} \frac{1}{U^i} \frac{\partial}{\partial u^i} \left(\frac{\sqrt{g}}{g_{ii}} \frac{dU^i}{du^i} \right) + (k)^2 \sqrt{g} = 0. \tag{4}$$

[3] The boldface numbers in parentheses refer to the references appended to this paper.

Evidently, a necessary condition for separability is that $\sqrt{g}/g_{ii}$ of Eq. 4 be expressible as a product:

$$\begin{cases} \dfrac{\sqrt{g}}{g_{11}} = f_1(u^1) \cdot F_1(u^2, u^3, \ldots u^n), \\ \dfrac{\sqrt{g}}{g_{22}} = f_2(u^2) \cdot F_2(u^1, u^3, \ldots u^n), \\ \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ \dfrac{\sqrt{g}}{g_{nn}} = f_n(u^n) \cdot F_n(u^1, u^2, \ldots u^{n-1}). \end{cases} \tag{5}$$

If this condition be satisfied, then Eq. 4 becomes

$$\sum_{i=1}^{n} \frac{F_i}{U^i} \frac{d}{du^i} \left(f_i \frac{dU^i}{du^i} \right) + (k)^2 \sqrt{g} = 0. \tag{6}$$

The partial derivatives have disappeared, but the equation is not yet in separable form because of the presence of F_i and $\sqrt{g}$.

The quantities $\sqrt{g}$, F_i, and f_i are characteristics of the coordinate system and are entirely independent of the boundary conditions. On the other hand, U^i depends on the coordinate system and on the separation constants $\alpha_1 = (k)^2, \alpha_2, \alpha_3, \ldots \alpha_n$, which are determined by the boundary conditions. Differentiation of Eq. 6 with respect to α_i gives the n equations,

$$\begin{cases} f_1F_1\Phi_{11}(u^1) + f_2F_2\Phi_{21}(u^2) + \ldots + f_nF_n\Phi_{n1}(u^n) = \sqrt{g}, \\ f_1F_1\Phi_{12}(u^1) + f_2F_2\Phi_{22}(u^2) + \ldots + f_nF_n\Phi_{n2}(u^n) = 0, \\ \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\ f_1F_1\Phi_{1n}(u^1) + f_2F_2\Phi_{2n}(u^2) + \ldots + f_nF_n\Phi_{nn}(u^n) = 0, \end{cases} \tag{7}$$

where, for convenience,

$$\Phi_{ij}(u^i) = -\frac{1}{f_i(u^i)} \frac{\partial}{\partial \alpha_j} \left[\frac{1}{U^i} \frac{d}{du^i} \left(f_i \frac{dU^i}{du^i} \right) \right], \tag{8}$$

$$(i, j = 1, 2, \ldots n).$$

Equation 7 constitutes a set of n simultaneous linear equations in the n unknowns (f_iF_i). In solving it, we use the *Stäckel determinant* (7):

$$S = \begin{vmatrix} \Phi_{11}(u^1) & \Phi_{12}(u^1) & \ldots & \Phi_{1n}(u^1) \\ \Phi_{21}(u^2) & \Phi_{22}(u^2) & \ldots & \Phi_{2n}(u^2) \\ \cdot \quad \cdot & \cdot \quad \cdot & \ldots & \cdot \quad \cdot \\ \Phi_{n1}(u^n) & \Phi_{n2}(u^n) & \ldots & \Phi_{nn}(u^n) \end{vmatrix}. \tag{9}$$

If $S \neq 0$, Eq. 7 has the solution

$$f_iF_i = \frac{\sqrt{g}}{S} M_{i1}, \tag{10}$$

where M_{i1} is the cofactor of the element Φ_{i1} in the Stäckel determinant.[4] Comparison of Eqs. 5 and 10 shows that

$$g_{ii} = \frac{S}{M_{i1}}, \tag{11}$$

which is the *first separability condition*. Also, from Eq. 10,

$$\frac{\sqrt{g}}{S} = \frac{f_1F_1}{M_{11}} = \frac{f_2F_2}{M_{21}} = \cdots = \frac{f_nF_n}{M_{n1}}, \tag{12}$$

which is possible only if

$$\frac{\sqrt{g}}{S} = \prod_{i=1}^{n} f_i(u^i). \tag{13}$$

Equation 13 constitutes the *second separability condition*.

We have shown that Eqs. 11 and 13 are *necessary* conditions for separability. There remains the proof that these conditions are also sufficient. From Eqs. 11 and 13,

$$\frac{\sqrt{g}}{g_{ii}} = \left[\prod_{i=1}^{n} f_i(u^i)\right] M_{i1},$$

and substitution in Eq. 4 gives

$$\sum_{i=1}^{n} \frac{1}{g_{ii}f_iU^i} \frac{d}{du^i}\left(f_i \frac{dU^i}{du^i}\right) + \alpha_1 = 0. \tag{14}$$

Expansion of the Stäckel determinant gives

$$\sum_{i=1}^{n} \Phi_{i1} \frac{M_{i1}}{S} = \sum \frac{\Phi_{i1}}{g_{ii}} = 1,$$

so we may write

$$\alpha_1 = \alpha_1 \sum_{i=1}^{n} \frac{\Phi_{i1}}{g_{ii}} + \alpha_2 \sum_{i=1}^{n} \frac{\Phi_{i2}}{g_{ii}} + \cdots + \alpha_n \sum_{i=1}^{n} \frac{\Phi_{in}}{g_{ii}}.$$

Substitution in Eq. 14 yields

$$\sum_{i=1}^{n} \frac{1}{g_{ii}} \left\{ \frac{1}{f_iU^i} \frac{d}{du^i}\left(f_i \frac{dU^i}{du^i}\right) + \sum_{j=1}^{n} \alpha_j \Phi_{ij}(u^i) \right\} = 0.$$

---

[4] The procedure, in setting up the Stäckel matrix, is as follows:

(1) A triply orthogonal set of coordinate surfaces is found. This step is outside the scope of the present paper.

(2) The metric coefficients and the Stäckel matrix are determined from the known equations for the given coordinate system. The Stäckel elements are found from Eq. 11.

Since vanishing or indeterminate metric coefficients have no meaning in euclidean space, we restrict ourselves to the case of $S \neq 0$.

This equation is satisfied in general only if each bracket is zero, or

$$\frac{1}{f_i}\frac{d}{du^i}\left(f_i\frac{dU^i}{du^i}\right) + U^i\sum_{j=1}^{n}\alpha_j\Phi_{ij} = 0, \qquad (15)$$

$$(i = 1, 2, \ldots n).$$

The Helmholtz equation has been reduced to n ordinary differential equations, and therefore Eqs. 11 and 13 are sufficient to give separation.

Theorem I. The necessary and sufficient conditions for simple separability of the Helmholtz equation, in euclidean n-space with an orthogonal coordinate system and with

$$\varphi = \varphi(u^1, u^2, \ldots u^n),$$

are that the metric coefficients satisfy the two equations:

$$\begin{cases} g_{ii} = \dfrac{S}{M_{i1}}, & (11) \\ \dfrac{\sqrt{g}}{S} = \prod_{i=1}^{n} f_i(u^i), & (13) \end{cases}$$

where S is the Stäckel determinant, Eq. 9.

2. *R*-SEPARABILITY OF THE HELMHOLTZ EQUATION

Now consider R-separability. Assume that the potential is

$$\varphi = \frac{U^1(u^1)\cdot U^2(u^2)\ \ldots\ U^n(u^n)}{R(u^1, u^2, \ldots u^n)} \qquad (16)$$

where R is a function to be defined later. Substitution into Eq. 1 yields

$$\sum_{i=1}^{n}\frac{1}{U^i}\frac{\partial}{\partial u^i}\left[\frac{\sqrt{g}}{g_{ii}}\left(\frac{1}{R}\frac{dU^i}{du^i} - \frac{U^i}{(R)^2}\frac{\partial R}{\partial u^i}\right)\right] + \frac{(k)^2\sqrt{g}}{R} = 0. \qquad (17)$$

If terms in $\partial R/\partial u^i$ are to be separated from those in dU^i/du^i, it is necessary that

$$\frac{\sqrt{g}}{g_{ii}} = (R)^2 f_i F_i, \qquad (18)$$

Substitution of Eq. 18 in (17), and multiplication by an arbitrary function $Q(u^1, u^2, \ldots u^n)$, gives

$$\sum_{i=1}^{n} F_i\left\{\frac{(R)^2 Q}{U^i}\frac{d}{du^i}\left(f_i\frac{dU^i}{du^i}\right) - RQ\frac{\partial}{\partial u^i}\left(f_i\frac{\partial R}{\partial u^i}\right)\right\} + (k)^2 Q\sqrt{g} = 0. \qquad (19)$$

This equation can be written in a form very similar to Eq. 6 if all the

unwanted terms are thrown into α_1:

$$\alpha_1 = (k)^2 Q - \frac{RQ}{\sqrt{g}} \sum_{i=1}^{n} F_i \frac{\partial}{\partial u^i}\left(f_i \frac{\partial R}{\partial u^i}\right).$$

Then Eq. 19 becomes

$$(R)^2 Q \sum_{i=1}^{n} \frac{F_i}{U^i} \frac{d}{du^i}\left(f_i \frac{dU^i}{du^i}\right) + \alpha_1 \sqrt{g} = 0 \tag{19a}$$

and we have as a necessary condition for separability:

$$\sum_{i=1}^{n} \frac{1}{f_i g_{ii}} \frac{\partial}{\partial u^i}\left(f_i \frac{\partial R}{\partial u^i}\right) + \left(\frac{\alpha_1}{Q} - (k)^2\right) R = 0. \tag{20}$$

Equation 20 constitutes a very stringent restriction on coordinate systems that allow R-separation.

Differentiating Eq. 19a with respect to $\alpha_1, \alpha_2, \ldots \alpha_n$, we obtain n linear equations in $(f_i F_i)$:

$$\begin{cases} f_1 F_1 \Phi_{11} + f_2 F_2 \Phi_{21} + \ldots + f_n F_n \Phi_{n1} = \dfrac{\sqrt{g}}{(R)^2 Q}, \\ f_1 F_1 \Phi_{12} + f_2 F_2 \Phi_{22} + \ldots + f_n F_n \Phi_{n2} = 0, \\ \quad \ldots \ldots \ldots \ldots \ldots \ldots \\ f_1 F_1 \Phi_{1n} + f_2 F_2 \Phi_{2n} + \ldots + f_n F_n \Phi_{nn} = 0, \end{cases} \tag{21}$$

where Φ_{ij} are defined by Eq. 8. The solutions of Eq. 21 are ($S \neq 0$)

$$f_1 F_1 = \frac{\sqrt{g}}{(R)^2 Q} \frac{M_{i1}}{S}, \tag{22}$$

and by Eq. 18,

$$g_{ii} = \frac{S}{M_{i1}} Q. \tag{23}$$

Equation 23 is similar to Eq. 11, though it plays a different rôle. It is not a restriction but is merely a definition of Q.

Also, from Eq. 22,

$$\frac{\sqrt{g}}{(R)^2 QS} = \frac{f_1 F_1}{M_{11}} = \frac{f_2 F_2}{M_{21}} = \ldots = \frac{f_n F_n}{M_{n1}}$$

so

$$\frac{\sqrt{g}}{QS} = \left[\prod_{i=1}^{n} f_i(u^i)\right](R)^2, \tag{24}$$

which may be regarded as a definition of R.

Now reconsider the necessary condition for R-separability, Eq. 20. The quantities f_i, g_{ii}, Q, and R depend only on the coordinate system; while $(k)^2$ is a physical parameter which is entirely independent of the

coordinates. The quantity α_1 is at most a function of $(k)^2$. Differentiation of Eq. 20 with respect to $(k)^2$ gives

$$\frac{d\alpha_1}{d(k)^2} = Q;$$

and since the left side is not a function of the coordinates, the right side must also be independent of u^i. Thus Q is a constant which, without loss of generality, can be set equal to unity, and

$$\alpha_1 = (k)^2 + A \tag{25}$$

where A is a constant of integration.

For R-separability of the Helmholtz equation, therefore, Eq. 20 becomes

$$\sum_{i=1}^{n} \frac{1}{f_i g_{ii}} \frac{\partial}{\partial u^i}\left(f_i \frac{\partial R}{\partial u^i}\right) + AR = 0. \tag{20a}$$

Also, since $Q = 1$, Eq. 23 becomes a restriction:

$$g_{ii} = \frac{S}{M_{i1}} \tag{23a}$$

while Eq. 24 continues to be a definition of R:

$$\frac{\sqrt{g}}{S} = \left[\prod_{i=1}^{n} f_i(u^i)\right](R)^2. \tag{24a}$$

That Eqs. 20*a* and 23*a* are also sufficient is shown by substitution, as in Section 1.

Theorem II. The necessary and sufficient conditions for R-separability of the Helmholtz equation, in euclidean n-space with an orthogonal coordinate system and with $\varphi = \varphi(u^1, u^2, \ldots u^n)$, *are*

$$\begin{cases} \displaystyle\sum_{i=1}^{n} \frac{1}{f_i g_{ii}} \frac{\partial}{\partial u^i}\left(f_i \frac{\partial R}{\partial u^i}\right) + AR = 0, & (20a) \\ \\ \displaystyle g_{ii} = \frac{S}{M_{i1}}, & (23a) \end{cases}$$

where R is determined from Eq. 24a.

3. SEPARABILITY OF THE LAPLACE EQUATION

Laplace's equation may be considered as a degenerate form of the Helmholtz equation with $k = 0$. Thus one might assume that the conditions for simple separability of the Laplace equation were the same as for the Helmholtz equation, which seems to be the assumption made by Morse and Feshbach (6). The difference between the two

cases consists in a change from inhomogeneous to homogeneous equations, which results in new separability conditions.

For simple separability, we proceed exactly as in Section 1, obtaining in place of Eq. 7 the homogeneous set of linear equations:

$$\begin{cases} f_1F_1\Phi_{11}(u^1) + f_2F_2\Phi_{21}(u^2) + \ldots + f_nF_n\Phi_{n1}(u^n) = 0, \\ f_1F_1\Phi_{12}(u^1) + f_2F_2\Phi_{22}(u^2) + \ldots + f_nF_n\Phi_{n2}(u^n) = 0, \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ f_1F_1\Phi_{1n}(u^1) + f_2F_2\Phi_{2n}(u^2) + \ldots + f_nF_n\Phi_{nn}(u^n) = 0, \end{cases} \tag{7a}$$

where Φ_{ij} are defined by Eq. 8. Solutions are

$$\frac{f_jF_j}{f_iF_i} = \frac{M_{j1}}{M_{i1}}. \tag{26}$$

But from Eq. 5,

$$\frac{f_jF_j}{f_iF_i} = \frac{g_{ii}}{g_{jj}},$$

so a necessary condition for the simple separability of Laplace's equation is

$$\frac{g_{ii}}{g_{jj}} = \frac{M_{j1}}{M_{i1}}. \tag{27}$$

Also, from Eq. 26,

$$f_1(u^1)\cdot\left[\frac{F_1(u^2, \ldots u^n)}{M_{11}(u^2, \ldots u^n)}\right] = f_2(u^2)\cdot\left[\frac{F_2}{M_{21}}\right] = \ldots = f_n(u^n)\cdot\left[\frac{F_n}{M_{n1}}\right],$$

which is satisfied only if each term is equal to $\prod f_i(u^i)$. Thus, from Eq. 5, we have the second necessary condition for separability:

$$\frac{\sqrt{g}}{g_{ii}} = \left[\prod_{i=1}^{n} f_i(u^i)\right]M_{i1}. \tag{28}$$

That Eqs. 27 and 28 are sufficient as well as necessary is proved as in Section 1 and leads to the same equations of separation [Eq. 15 with $\alpha_1 = 0$].

Theorem III. The necessary and sufficient conditions for simple separability of Laplace's equation, in euclidean n-space with an orthogonal coordinate system and with $\varphi = \varphi(u^1, u^2, \ldots u^n)$, *are*

$$\begin{cases} \dfrac{g_{ii}}{g_{jj}} = \dfrac{M_{j1}}{M_{i1}}, \text{ and} & (27) \\ \dfrac{\sqrt{g}}{g_{ii}} = \left[\displaystyle\prod_{i=1}^{n} f_i(u^i)\right]M_{i1}. & (28) \end{cases}$$

For R-separability of the Laplace equation, homogeneous equations do not appear and the results of Section 2 are directly applicable with $k = 0$, $Q \neq 1$, and $\alpha_1 = A$.

Theorem IV. The necessary and sufficient condition for R-separability of Laplace's equation, in euclidean n-space with an orthogonal coordinate system and with $\varphi = \varphi(u^1, u^2, \ldots u^n)$, *is*

$$\sum_{i=1}^{n} \frac{1}{f_i g_{ii}} \frac{\partial}{\partial u^i}\left(f_i \frac{\partial R}{\partial u^i}\right) + \alpha_1 \frac{R}{Q} = 0, \tag{20b}$$

where

$$g_{ii} = \frac{S}{M_{i1}} Q \tag{23}$$

and

$$\frac{\sqrt{g}}{QS} = \left[\prod_{i=1}^{n} f_i(u_i^i)\right](R)^2. \tag{24}$$

4. EQUIVALENT STÄCKEL MATRICES

A matrix,

$$[\Phi_{ij}(u^j)]$$

whose elements correspond to those of the Stäckel determinant S, may be called a *Stäckel matrix*. Evidently a 1:1 correspondence does not exist between a Stäckel matrix and a coordinate system. A certain degree of flexibility is possible in the arrangement and evaluation of the elements Φ_{ij}, and it is this flexibility which will now be considered.

Two Stäckel matrices are said to be *equivalent* if the ratios S/M_{i1} (and hence the metric coefficients g_{ii}) are the same for each matrix. Therefore, by elementary determinant theory, two Stäckel matrices are equivalent if one can be obtained from the other by one or more of the following operations:

1. Interchange of ith and jth columns, where $i, j = 2, 3, \ldots n$.
2. Multiplication of each element of the jth column by a constant not equal to zero.
3. Addition of each element in the ith column to the corresponding element in the jth column $(i, j = 2, 3, \ldots n)$.

Note that operations on rows are ordinarily not permissible. Also, the first column holds a privileged position and must not be altered.

5. CYLINDRICAL COORDINATE SYSTEMS

Most practical problems deal with either cylindrical or rotational coordinates in 3-space; in both of which cases the separability conditions are simplified. First take cylindrical coordinates (u^1, u^2, u^3). The coordinate surfaces consist of two mutually orthogonal families of cylinders, plus a family of parallel planes. The metric coefficients for a cylindrical

system depend on only two coordinates instead of three:

$$\begin{cases} g_{11} = g_{11}(u^1, u^2), \\ g_{22} = g_{22}(u^1, u^2), \\ g_{33} = 1. \end{cases}$$

A change of variables always allows us to write

$$g_{11} = g_{22} = \sqrt{g}, \tag{29}$$

and, in the following paragraphs, this condition will be assumed to hold.

For simple separability of the Helmholtz equation, Eqs. 11 and 13 become

$$g_{11} = g_{22} = \frac{S}{M_{11}} = \frac{S}{M_{21}}, \tag{11a}$$

$$g_{33} = 1 = \frac{S}{M_{31}}, \tag{11b}$$

$$\frac{\sqrt{g}}{S} = \frac{g_{11}}{S} = f_1(u^1) \cdot f_2(u^2), \tag{13a}$$

and

$$[S] = \begin{bmatrix} \Phi_{11}(u^1) & \Phi_{12}(u^1) & \Phi_{13}(u^1) \\ \Phi_{21}(u^2) & \Phi_{22}(u^2) & \Phi_{23}(u^2) \\ \Phi_{31}(u^3) & \Phi_{32}(u^3) & \Phi_{33}(u^3) \end{bmatrix}.$$

Since the metric coefficients do not contain u^3, the third row of $[S]$ can contain only constants. From Eq. 11*b*,

$$S = M_{31},$$

so $\Phi_{11} = \Phi_{21} = 0$, $\Phi_{31} = 1$. Use of the allowable operations of Section 4 then puts the Stäckel matrix in form,

$$[S] = \begin{bmatrix} 0 & \Phi_{12} & \Phi_{13} \\ 0 & \Phi_{22} & \Phi_{23} \\ 1 & 0 & 1 \end{bmatrix}.$$

But by Eq. 11*a*,

$$M_{11}(u^2) = M_{21}(u^1) = \text{const.},$$

or, from Section 4, $\Phi_{22} = -\Phi_{12} = 1$. Thus the Stäckel determinant for any cylindrical coordinate system may be written

$$S = \begin{vmatrix} 0 & -1 & \Phi_{13} \\ 0 & 1 & \Phi_{23} \\ 1 & 0 & 1 \end{vmatrix} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)]. \tag{30}$$

Moreover, $M_{11} = M_{21} = 1$, so we can write $f_1 = f_2 = 1$ in Eq. 13*a*, and the sole requirement for separability is that g_{11} be expressible as a sum:

$$g_{11} = g_{22} = S = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)].$$

Theorem V. The necessary and sufficient condition for simple separability of the Helmholtz equation, in euclidean 3-space with orthogonal cylindrical coordinates and with $\varphi = \varphi(u^1, u^2, u^3)$, *is*

$$g_{11} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)]. \tag{31}$$

The separation equations are

$$\frac{d^2U^i}{(du^i)^2} + U^i \sum_{j=1}^{3} \alpha_j \Phi_{ij} = 0 \tag{15a}$$

where $\alpha_1 = (k)^2$, *and the Stäckel determinant is given by Eq. 30.*

For simple separability of the Laplace equation, we use the same Stäckel determinant, Eq. 30; but separation now requires Theorem III, and thus

$$g_{11} = g_{22} = \frac{M_{31}}{M_{11}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)].$$

Theorem VI. The necessary and sufficient condition for simple separability of the Laplace equation, in euclidean 3-space with orthogonal cylindrical coordinates and with $\varphi = \varphi(u^1, u^2, u^3)$, *is*

$$g_{11} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)]. \tag{31}$$

Separation equations are given by Eq. 15*a* with $\alpha_1 = 0$.

For R-separability, the Stäckel determinant is kept as in Eq. 30, in accordance with Section 4. From Eqs. 23 and 24,

$$g_{33} = 1 = \frac{S}{M_{31}} Q, \tag{23b}$$

$$\frac{\sqrt{g}}{QS} = \frac{g_{11}}{QS} = f_1 f_2 (R)^2. \tag{24b}$$

Thus $Q = 1$, $R = 1$, and there is no R-separability. This conclusion applies equally to Helmholtz and Laplace equations.

Theorem VII. The Helmholtz and Laplace equations are never R-separable in any cylindrical coordinate system.

6. ROTATIONAL COORDINATE SYSTEMS

Consider a euclidean 3-space and a coordinate system having symmetry about an axis. The potential distribution, however, is not symmetrical but is $\varphi = \varphi(u^1, u^2, u^3)$. The metric coefficients contain only two space variables, so it is always possible to write

$$g_{11}(u^1, u^2) = g_{22}(u^1, u^2), \quad g_{33} = g_{33}(u^1, u^2).$$

Therefore, the third row of the Stäckel determinant can contain only constants. Making use of Eqs. 11 and 13 as in Section 5, we find for

rotational coordinates,

$$S = \begin{vmatrix} \Phi_{11} & -1 & \Phi_{13} \\ \Phi_{21} & 1 & \Phi_{23} \\ 0 & 0 & 1 \end{vmatrix} = \Phi_{11}(u^1) + \Phi_{21}(u^2). \tag{32}$$

From Eq. 11 for simple separability of the Helmholtz equation,

$$g_{11} = S = \Phi_{11}(u^1) + \Phi_{21}(u^2), \tag{33}$$

which restricts g_{11} to a sum of separated functions. From Eq. 11,

$$\frac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)], \tag{34}$$

so g_{11}/g_{33} must likewise be a separated sum. Also, from Eq. 13, g_{33} must be a product:

$$g_{33} = [f_1(u^1) \cdot f_2(u^2)]^2. \tag{35}$$

Theorem VIII. The necessary and sufficient conditions for simple separability of the Helmholtz equation, in euclidean 3-space with orthogonal rotational coordinate systems and with $\varphi = \varphi(u^1, u^2, u^3)$, are given by Eqs. 33, 34, and 35.

For Laplace's equation in rotational coordinates, the Stäckel determinant remains as in Eq. 32. Also, Eqs. 27 and 28 give

$$\frac{g_{11}}{g_{33}} = \frac{M_{21}}{M_{11}} = \frac{-(\Phi_{13} + \Phi_{23})}{1}$$

and

$$\frac{\sqrt{g}}{S} = g_{33} = (f_1 f_2)^2.$$

Theorem IX. The necessary and sufficient conditions for simple separability of the Laplace equation, in euclidean 3-space with orthogonal rotational coordinate systems and with $\varphi = \varphi(u^1, u^2, u^3)$, are

$$\begin{cases} \dfrac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)], & (34) \\ g_{33} = [f_1(u^1) \cdot f_2(u^2)]^2. & (35) \end{cases}$$

For R-separability in rotational coordinates, we keep Eq. 32, and

$$\sum_{i=1}^{2} \frac{1}{f_i g_{ii}} \frac{\partial}{\partial u^i}\left(f_i \frac{\partial R}{\partial u^i}\right) + \left[\frac{\alpha_1}{Q} - (k)^2\right] R = 0, \tag{20}$$

$$g_{ii} = \frac{S}{M_{i1}} Q, \tag{23}$$

$$\frac{\sqrt{g}}{QS} = f_1 f_2 (R)^2. \tag{24}$$

Equation 23 gives a definition of Q:

$$g_{11} = (\Phi_{11} + \Phi_{21})Q, \tag{23c}$$

and a restriction:

$$\frac{g_{11}}{g_{33}} = -(\Phi_{13} + \Phi_{23}). \tag{34}$$

Equation 24 gives a definition for R:

$$\frac{g_{11}\sqrt{g_{33}}}{(\Phi_{11} + \Phi_{21})Q} = \sqrt{g_{33}} = f_1 f_2 (R)^2. \tag{24c}$$

Reference to Sections 2 and 3 leads to the following conclusions:

Theorem X. The necessary and sufficient conditions for R-separability of the Helmholtz equation, in euclidean 3-space with orthogonal rotational coordinates and with $\varphi = \varphi(u^1, u^2, u^3)$, *are*

$$\begin{cases} \dfrac{1}{f_1}\dfrac{\partial}{\partial u^1}\left(f_1 \dfrac{\partial R}{\partial u^1}\right) + \dfrac{1}{f_2}\dfrac{\partial}{\partial u^2}\left(f_2 \dfrac{\partial R}{\partial u^2}\right) + A(\Phi_{11} + \Phi_{21})R = 0, & (36) \\ g_{11} = \Phi_{11}(u^1) + \Phi_{21}(u^2), & (33) \\ \dfrac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)], & (34) \end{cases}$$

where R is defined by the equation,

$$g_{33} = [f_1(u^1) \cdot f_2(u^2)]^2 (R)^4 \tag{37}$$

and where A is a constant.

Theorem XI. The necessary and sufficient conditions for R-separability of the Laplace equation, in euclidean 3-space with orthogonal rotational coordinates and with $\varphi = \varphi(u^1, u^2, u^3)$, *are*

$$\begin{cases} \dfrac{1}{f_1}\dfrac{\partial}{\partial u^1}\left(f_1 \dfrac{\partial R}{\partial u^1}\right) + \dfrac{1}{f_2}\dfrac{\partial}{\partial u^2}\left(f_2 \dfrac{\partial R}{\partial u^2}\right) + \alpha_1(\Phi_{11} + \Phi_{21})R = 0, & (36) \\ \dfrac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)], & (34) \end{cases}$$

where

$$g_{11} = [\Phi_{11}(u^1) + \Phi_{21}(u^2)]Q \text{ and} \tag{23c}$$

$$g_{33} = [f_1(u^1) \cdot f_2(u^2)]^2 (R)^4. \tag{37}$$

7. CONCLUSIONS

New coordinate systems are often needed in potential theory, and in each case the question arises as to the possibility of separation of the Laplace and Helmholtz equation in these new coordinates. The paper

establishes necessary and sufficient conditions for separability, and these results are summarized in Tables I, II, and III. Table I lists general conditions for simple separability and R-separability in euclidean n-space, while Tables II and III give the corresponding requirements for cylindrical and for rotational coordinates in 3-space.

TABLE I.—*Separation of Partial Differential Equations.*
In euclidean n-space with $\varphi = \varphi(u^1, u^2, \dots u^n)$.

	Schrödinger	Helmholtz	Laplace
Equation	$\nabla^2\varphi + (k)^2(E-V)\varphi = 0$	$\nabla^2\varphi + (k)^2\varphi = 0$	$\nabla^2\varphi = 0$
SIMPLE SEPARABILITY	$\varphi = U^1U^2U^3$	$\varphi = U^1U^2U^3$	$\varphi = U^1U^2U^3$
Separability conditions	$g_{ii} = \dfrac{S}{M_{i1}}$, $\dfrac{\sqrt{g}}{S} = \prod_{i=1}^{n} f_i(u^i)$, $V = \sum_{i=1}^{n} \dfrac{M_{i1}}{S}\chi_i(u^i)$.	$g_{ii} = \dfrac{S}{M_{i1}}$, $\dfrac{\sqrt{g}}{S} = \prod_{i=1}^{n} f_i(u^i)$.	$g_{ii} = \dfrac{M_{j1}}{M_{i1}}$, $\dfrac{\sqrt{g}}{g_{ii}} = \left[\prod_{i=1}^{n} f_i(u^i)\right] M_{i1}$.
Separated equations	$\dfrac{1}{f_i}\dfrac{d}{du^i}\left(f_i\dfrac{dU^i}{du^i}\right) + (k)^2U^i\left\{\sum_{j=1}^{n}\alpha_j\Phi_{ij} - \chi_i(u^i)\right\} = 0$, where $i, j = 1, 2, \dots n$.	$\dfrac{1}{f_i}\dfrac{d}{du^i}\left(f_i\dfrac{dU^i}{du^i}\right) + U^i\sum_{j=1}^{n}\alpha_j\Phi_{ij} = 0$, where $i, j = 1, 2, \dots n$.	$\dfrac{1}{f_i}\dfrac{d}{du^i}\left(f_i\dfrac{dU^i}{du^i}\right) + U^i\sum_{j=1}^{n}\alpha_j\Phi_{ij} = 0$, where $\alpha_1 = 0$.
α_1	E	$(k)^2$	0
R-SEPARABILITY	$\varphi = \dfrac{U^1U^2U^3}{R}$	$\varphi = \dfrac{U^1U^2U^3}{R}$	$\varphi = \dfrac{U^1U^2U^3}{R}$
Separability conditions		$\sum_{i=1}^{n}\dfrac{1}{f_ig_{ii}}\dfrac{\partial}{\partial u^i}\left(f_i\dfrac{\partial R}{\partial u^i}\right) + AR = 0$, $g_{ii} = \dfrac{S}{M_{i1}}$.	$\sum_{i=1}^{n}\dfrac{1}{f_ig_{ii}}\dfrac{\partial}{\partial u^i}\left(f_i\dfrac{\partial R}{\partial u^i}\right) + \alpha_1\dfrac{R}{Q} = 0$.
Defining equations		$\dfrac{\sqrt{g}}{S} = \left[\prod_{i=1}^{n} f_i(u^i)\right](R)^2$, $A = \text{const.}$	$g_{ii} = \dfrac{S}{M_{i1}}Q$, $\dfrac{\sqrt{g}}{QS} = \left[\prod_{i=1}^{n} f_i(u^i)\right](R)^2$.
Separated equations		$\dfrac{1}{f_i}\dfrac{d}{du^i}\left(f_i\dfrac{dU^i}{du^i}\right) + U^i\sum_{j=1}^{n}\alpha_j\Phi_{ij} = 0$.	$\dfrac{1}{f_i}\dfrac{d}{du^i}\left(f_i\dfrac{dU^i}{du^i}\right) + U^i\sum_{j=1}^{n}\alpha_j\Phi_{ij} = 0$.
α_1		$(k)^2 + A$	Determined from separability equation

TABLE II.—*Cylindrical Coordinate Systems.*
In euclidean 3-space with $\varphi = \varphi(u^1, u^2, u^3)$ and $g_{11} = g_{22}$.

	Helmholtz	Laplace
Equation	$\nabla^2\varphi + (k)^2\varphi = 0$	$\nabla^2\varphi = 0$
SIMPLE SEPARABILITY	$\varphi = U^1U^2U^3$	$\varphi = U^1U^2U^3$
Separability conditions	$g_{11} = -[\Phi_{12}(u^1) + \Phi_{22}(u^2)]$.	$g_{11} = -[\Phi_{12}(u^1) + \Phi_{22}(u^2)]$.
Separated equations	$\dfrac{d^2U^i}{(du^i)^2} + U^i \sum_{j=1}^{3} \alpha_j\Phi_{ij} = 0,$ $i, j = 1, 2, 3.$	$\dfrac{d^2U^i}{(du^i)^2} + U^i \sum_{j=1}^{3} \alpha_j\Phi_{ij} = 0.$ where $\alpha_1 = 0$.
α_1	$(k)^2$	0
R-SEPARABILITY	Not possible	Not possible
Stackel determinant for any cylindrical system	$\begin{vmatrix} 0 & -1 & \Phi_{13} \\ 0 & 1 & \Phi_{23} \\ 1 & 0 & 1 \end{vmatrix}$ $= -[\Phi_{13} + \Phi_{23}]$.	$\begin{vmatrix} 0 & -1 & \Phi_{13} \\ 0 & 1 & \Phi_{23} \\ 1 & 0 & 1 \end{vmatrix}$ $= -[\Phi_{13} + \Phi_{23}]$.

TABLE III.—*Rotational Coordinate Systems.*
In euclidean 3-space with $\varphi = \varphi(u^1, u^2, u^3)$ and $g_{11} = g_{22}$.

	Helmholtz	Laplace
Equation	$\nabla^2\varphi + (k)^2\varphi = 0$	$\nabla^2\varphi = 0$
SIMPLE SEPARABILITY	$\varphi = U^1U^2U^3$	$\varphi = U^1U^2U^3$
Separability conditions	$g_{11} = \Phi_{11}(u^1) + \Phi_{21}(u^2)$, $\dfrac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)]$, $g_{33} = [f_1(u^1) \cdot f_2(u^2)]^2$.	$\dfrac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)]$, $g_{33} = [f_1(u^1) \cdot f_2(u^2)]^2$.
Separated equations	$\dfrac{1}{f_i}\dfrac{d}{du^i}\left(f_i \dfrac{dU^i}{du^i}\right)$ $+ U^i \sum_{j=1}^{3} \alpha_j\Phi_{ij} = 0,$ where $i, j = 1, 2, \ldots n$.	$\dfrac{1}{f_i}\dfrac{d}{du^i}\left(f_i \dfrac{dU^i}{du^i}\right)$ $+ U^i \sum_{j=1}^{3} \alpha_j\Phi_{ij} = 0,$ where $\alpha_1 = 0$.
α_1	$(k)^2$	0
R-SEPARABILITY	$\varphi = \dfrac{U^1U^2U^3}{R}$	$\varphi = \dfrac{U^1U^2U^3}{R}$
Separability conditions	$\dfrac{1}{f_1}\dfrac{\partial}{\partial u^1}\left(f_1 \dfrac{\partial R}{\partial u^1}\right) + \dfrac{1}{f_2}\dfrac{\partial}{\partial u^2}\left(f_2 \dfrac{\partial R}{\partial u^2}\right)$ $+ A(\Phi_{11} + \Phi_{21})R = 0,$ $g_{11} = \Phi_{11}(u^1) + \Phi_{21}(u^2)$, $\dfrac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)]$.	$\dfrac{1}{f_1}\dfrac{\partial}{\partial u^1}\left(f_1 \dfrac{\partial R}{\partial u^1}\right) + \dfrac{1}{f_2}\dfrac{\partial}{\partial u^2}\left(f_2 \dfrac{\partial R}{\partial u^2}\right)$ $+ \alpha_1(\Phi_{11} + \Phi_{21})R = 0,$ $\dfrac{g_{11}}{g_{33}} = -[\Phi_{13}(u^1) + \Phi_{23}(u^2)]$.

TABLE III.—*Continued.*

	Helmholtz	Laplace
Equation	$\nabla^2\varphi+(k)^2\varphi=0$	$\nabla^2\varphi=0$
Defining equations	$g_{33}=[f_1(u^1)\cdot f_2(u^2)]^2(R)^4.$	$g_{11}=[\Phi_{11}(u^1)+\varphi_{21}(u^2)]Q,$ $g_{33}=[f_1(u^1)\cdot f_2(u^2)]^2(R)^4.$
Separated equations	$\frac{1}{f_i}\frac{d}{du^i}\left(f_i\frac{dU^i}{du^i}\right)$ $+U^i\sum_{j=1}^{3}\alpha_j\Phi_{ij}=0,$ where $i,j=1,2,3.$	$\frac{1}{f_i}\frac{d}{du^i}\left(f_i\frac{dU^i}{du^i}\right)$ $+U^i\sum_{j=1}^{3}\alpha_j\Phi_{ij}=0,$ where $i,j=1,2,3.$
α_1	$(k)^2+A$	Obtained from first separability condition.
Stäckel determinant for any rotational system	$\begin{vmatrix}\Phi_{11} & -1 & \Phi_{13}\\ \Phi_{21} & 1 & \Phi_{23}\\ 0 & 0 & 1\end{vmatrix}$ $=\Phi_{11}+\Phi_{21}$	$\begin{vmatrix}\Phi_{11} & -1 & \Phi_{13}\\ \Phi_{21} & 1 & \Phi_{23}\\ 0 & 0 & 1\end{vmatrix}$ $=\Phi_{11}+\Phi_{21}$

In all cases, conditions are investigated for a potential that depends on all coordinates (n coordinates in Table I and three coordinates in Tables II and III). In many problems, however, the potential is a function of only one or two independent variables, which tends to lighten the restrictions on the coordinate system. These degenerate cases will be investigated in another paper (8).

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS *

SOLAR RADIO NOISE BURSTS

Solar investigations by the National Bureau of Standards have led to the discovery of a phenomenon that appears to be another source of interference to long-range radio reception. The phenomenon is observed as bursts of solar radio noise superimposed on a normally steady level of radio-frequency energy received from the sun. The background radiation is presumed to be thermally produced in the extremely hot regions of the solar atmosphere. Dr. J. Feinstein of the NBS Central Radio Propagation Laboratory recently made a comprehensive analysis of the radio noise bursts using data obtained by the methods of radio astronomy. From the data, it was concluded[1] that the bursts are not of the same thermal origin as the background but are the end result of the direct conversion to electromagnetic energy of the kinetic energy in the corona.

In recent years, investigations of outer-space phenomena have been immeasurably aided by radio astronomy. The method was instrumental in determining the existence of the quiescent level of electromagnetic energy (background radiation) surrounding the sun. The origin of this radio-frequency energy was thought to be thermal; but in order for this to be true, the temperature of the emitting region would have to be around one million degrees Kelvin, even though established theories recognized a solar surface temperature of only about 6000° K. However, evidence obtained mainly from the spectra of the highly ionized atoms present was sufficiently strong to bring about the acceptance of the higher value as the temperature of the corona. The mechanism by which this temperature inversion is brought about has still not been conclusively settled.

Radio astronomy methods were used at the National Bureau of Standards to observe the burst of radio energy. A non-thermal origin has been ascribed to them because their energies were found to be sometimes several orders of magnitude greater than the background radiations. The theory proposed by NBS is in accordance with the second law of thermodynamics, which imposes no limitations on the conversion of mechanical energy from one form to another. The source of directed energy in the solar region lies in the many high-velocity streams composed of ionized gases containing equal numbers of positively and negatively charged particles. As a result of their motion, these "plasmas," as they are called, contain sufficient energy to account for

* Communicated by the Director.

[1] This conclusion is based, in part, on a suggestion by A. V. Heaff, Naval Research Laboratory.

the bursts, but their energy is, of course, in the kinetic form. Some means is required to convert this energy into the radio-frequency energy that is observed.

A mechanism that converts energy similar to that of the plasmas into the electromagnetic flow was found in the microwave vacuum tube laboratory. At low frequencies, electrical oscillations are produced by sharply resonant circuits that develop fields to act upon streams of electrons inside conventional vacuum tubes. However, at higher frequencies, transit-time effects destroy the phase relations required for proper field-particle interaction in this type of tube. With the subsequent development of the traveling wave tube, it was realized that tuned circuits are not an absolute necessity in the generation of electrical energy. This type of tube employs a helix or equivalent structure capable of guiding an electromagnetic wave at reduced speed so that it can interact, energy-wise, with a beam of electrons. Further experimentation resulted in the development of a tube that employs a second beam to carry the wave—the so-called double-stream amplifier. Although this tube is still in the developmental stage, its principle of operation appears to parallel the non-thermal generation of radio-waves occurring in nature.

The Bureau's analysis of these "plasma oscillations" is based on the fact that if a fluctuation of any sort occurs in a system composed of otherwise uniform streams of moving charges, the frequency components in the fluctuation which lie within certain bands will be amplified. The nature and extent of these bands are determined by the velocities and charge densities of the uniform streams. The action may be visualized by considering the electric field that is produced by the initial fluctuation of the charged particles contained in one of the streams. This field agitates adjacent particles, and the resulting variations in density are carried along in the streams. These, in turn, will produce their own electric fields—will in effect, multiply or amplify the original fluctuation. The action continues, tending to increase the density variations so that a bunching results, giving rise to a space charge wave that grows as it travels. Hence, by means of this wave growth, a fluctuation, initially of negligible energy content, acquires a sizable fraction of the total uniform kinetic energy possessed by the whole system.

To determine the electromagnetic radiation emitted by this type of system, the usual antenna theory is applied. Thus, the traveling space charge wave is considered equivalent to an oscillating current, and the condition for it to give rise to a strong radiated field is similar to the condition for a circuit element to act as an antenna: the spatial change of the amplitude of the current must be large, within a wavelength of the generated oscillation. Small-signal theory calculations indicate that this condition is satisfied in the growth region, but a larger-signal, nonlinear theory is required to really establish this fact. Work is proceeding on such a theory.

More recently, Dr. H. K. Sen, also of the NBS Central Radio Propagation Laboratory, has been conducting theoretical investigations[2] of the effects of plasma oscillations in a system of electrons gyrating around a static magnetic field near the surface of the sun. Radio astronomy data have indicated that certain types of enhanced radiations proceed from the direction of sunspots and show circular polarization.

It is assumed that when prominences move with high velocities in the magnetic field of a sunspot in a direction oblique to the lines of force, the free electrons are set to describing circular spirals. They, in turn, generate electric fields, and the interplay of these forces produces oscillations of the correct frequency to emit radio energy.

Ordinary collisions between particles in the prominence gases do not produce results resembling the observed radio effects. However, it appears that any distortion of the electron distribution will be repeated with the gyroperiod of the electrons. The space-charge electric field will vary with the same period, achieving an effect similar to that in a cyclotron. The energy would thus be built up or amplified to an extraordinary degree. From such a mechanism, the energy emission would be circularly or elliptically polarized, agreeing with the observed polarization of radio noise storms.

As a numerical illustration of the phenomenon, consider a sunspot magnetic field of about 30 gauss at coronal distances of about 10^{10} cm above the photosphere (the intensely bright portion of the sun that is visible to the unaided eye) and an electron density of the moving prominence of about $5 \times 10^9/\text{cm}^3$. This combination of elements will result in an amplification of the plasma oscillation sufficiently large to emit radio energy in the frequency range 70 and 130 Mc, as observed by radio astronomers in Australia. Further, the large frequency band width over which amplification is available enables the radiation to escape through regions that are normally overdense for the gyrofrequency.

Besides the accumulated evidence that these solar radio noise bursts are another possible source of interference, there seems to be some regular association between the bursts and sudden ionosphere disturbances. There are indications of a decided tendency for the bursts either to accompany, to precede, or to follow flurries of activity on the sun. It is hoped that when sufficient experimental data have been collected and analysed, the presence of solar radio noise bursts can be used as an additional warning of interruptions to radio propagation.

AN AUTOMATIC LIQUID NITROGEN DISPENSER

A very simple method for automatically dispensing liquid nitrogen to vacuum-system traps and other vessels has recently been developed by Jesse Sherwood of the National Bureau of Standards. The new tech-

[2] Dr. Sen's work is based on an investigation by K. Malmfors, Swedish physicist.

nique permits the maintenance of a liquid refrigerant in a system for long periods of time without the use of an external source of compressed air.

In most vacuum systems, the evacuated apparatus is kept free of contaminating gaseous matter by trapping the vapors before they circulate throughout the system. A trap, filled with some refrigerant such as dry ice or liquid nitrogen, is inserted into the system so that as the vapors pass over it, they condense and collect on the surface of the trap. However, these refrigerants evaporate rapidly and hence must be replenished at regular intervals. The NBS dispenser automatically performs this task, keeping the trap filled to any predetermined level for a period of time dependent only on the available supply of liquid nitrogen.

The NBS automatic dispensing technique utilizes two simple principles: that a confined liquid, when heated, will partially evaporate and thereby raise the internal pressure of the container high enough to force the liquid through any prepared orifice; and that a mercury column, besides being sensitive to change in pressure, is also a conductor of electricity. Thus the dispenser consists essentially of a simple gas thermometer, a mercury pressure gage, a confined source of liquid nitrogen, and a nichrome-wire heater.

The gas thermometer, suspended in the trap, reacts to the temperature at some point near the desired level of liquid nitrogen. If the liquid nitrogen level is low, the gas (air) in the thermometer expands and forces mercury to flow in a U-tube. A pair of wires are present in the mercury column so that as the mercury surface rises (with the rise in temperature and pressure) the external electric circuit between the two wires is completed. This switching effect applies 25 watts of power to a nichrome-wire heater at the bottom of the liquid nitrogen container. The ensuing evaporation generates gaseous nitrogen, and the subsequent increase in pressure forces the liquid nitrogen through a connecting tube to the trap. As the level of the liquid in the trap rises, the thermometer cools, the gas pressure decreases, the mercury column in the U-tube drops, the electric circuit is disconnected, and the flow of liquid nitrogen stops.

A vent in the delivery tube prevents excessive bubbling of the liquid in the trap. A bleeder valve on the liquid nitrogen container is also provided to remove gaseous nitrogen resulting from natural evaporation; adjustment of this valve is not critical. The U-tube should have an inner diameter of at least 6 mm.

NOTES FROM THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT

A PROGRESS REPORT ON THE NARC

A year ago, in the May 1951 number of the JOURNAL OF THE FRANKLIN INSTITUTE, readers were introduced to the National Asphalt Research Center. During the intervening year the Research Center has made very satisfactory progress toward achieving a complete asphalt technology. During its first year of research, the NARC has shown that industrial research done on a cooperative-sponsorship basis is one of the more important developments of the Laboratories' research-for-industry theme.

To summarize briefly the purposes of the NARC, the facilities of the Research Center are devoted to taking the first three steps of a four-step program for acquiring a complete technology. The first is to define and measure the fundamental properties of asphalts. The second, to correlate these properties to the engineering characteristics they control. The third, to correlate these properties to the important structure and composition variables. The fourth step, taken by the sponsors, is to apply this knowledge to their own raw materials and processing in order to formulate improved asphalts and asphalt products that have new applications.

The greater part of the first year's work has, as planned, been devoted to investigations into the fundamental properties of asphalts. Disclosure of several hitherto unsuspected facts concerning fundamental properties attest to the vigor and success with which the first step of the program has been attacked. In the second year, although much of the work will be directed to extending and refining the fundamental work, considerable effort will be given to applying this fundamental information to engineering requirements. It is expected that as a result sponsors will be furnished tangible rewards for their foresightedness in underwriting this major research program.

The roster of sponsors has grown to include twenty-six companies, twenty-one of which were founders. This indicates that the industry is growing to realize the desirability of establishing a more scientific asphalt technology in order to develop the new and better products that insure their continued prosperity. More evidence of this increasing interest was seen at the annual meeting of the NARC in February. Fifty-three technical personnel representing twenty-five sponsors met with Laboratories' researchers at The Franklin Institute on February 28

and 29 to review the first year's work and to plan for activities during the second year. Aside from an active exchange of ideas, the technical sessions were highlighted by the presentation of papers by three sponsors' representatives. Conferences of this sort channel the Research Center's activity to serve the best interests of the sponsoring group, and to supplement the reports of progress submitted to the sponsors throughout the year.

It is foreseen that new sponsors will be attracted to the program as a consequence of the NARC's continued successful activity, and that ultimately the public will realize the benefits of this "research partnership" when new and improved products reach the market.

THE FRANKLIN INSTITUTE

MINUTES OF THE STATED MEETING

May 21, 1952

The Stated Monthly Meeting of The Franklin Institute was held on May 21, 1952, in the Lecture Hall of The Franklin Institute. S. Wyman Rolph, President, called the meeting to order at 8:20 P.M. Approximately 110 persons attended.

The President stated that the Minutes of the Stated Monthly Meeting in March were printed in full in the April JOURNAL, and the Minutes of the Stated Monthly Meeting in April were printed in full in the May JOURNAL. No corrections or additions being submitted, they were approved as printed.

The President drew attention to the May JOURNAL, with its unusual cover, which commemorated the 200th anniversary of Benjamin Franklin's famous lightning rod invention.

He then summarized the Annual Report of the Board of Managers for 1951 and announced that the complete Report would appear in the July issue of the JOURNAL.

The Secretary stated that Dr. Wolfgang Pauli, Franklin Medallist for 1952, had been nominated by the Board of Managers for Honorary Membership in The Franklin Institute. In accordance with the provisions of the By-Laws, upon motion made and seconded, Dr. Pauli was duly elected to Honorary Membership.

The Secretary reported the following elections to membership for the month of April:

Active	34
Associate	39
Student	16

and a total Institute membership of 6,332 as of April 30, 1952.

He announced that June would be observed as Girl Scout Month in the Planetarium, where the demonstration will be "Stars of a Summer Night." He also announced that International Business Machines Corporation would sponsor an exhibit of models in Franklin Hall from June 24th to July 27th, illustrating Leonardo da Vinci's many inventions.

The President drew attention to the exhibit of Ford Motor Company's Industrial Arts Awards in Franklin Hall to be held from June 4th to June 8th.

The President then introduced the speaker for the evening, Mr. H. Birchard Taylor (Engineer, Industrialist and Author), whose topic was "Charles Day—Symbol of American Industrial Genius." This 1952 Charles Day Lecture will be published in the July issue of the JOURNAL.

The meeting adjourned at 9:45 P.M. with a rising vote of thanks to Mr. Taylor.

HENRY B. ALLEN,
Secretary

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, May 14, 1952.)

HALL OF THE COMMITTEE,
PHILADELPHIA, MAY 14, 1952.

MR. HOWARD STOERTZ in the Chair.

The following reports were presented for final action:

No. 3249: Henderson Medal.

This report recommended the award of the George R. Henderson Medal to Alfred J. Büchi, of Winterthür, Switzerland, "In view of his contributions in augmenting the capacity and performance of the four-cycle Diesel engine through his supercharging system in all classes of service, but particularly in the railway field."

No. 3251: Clark Medal.

This report recommended the award of the Walton Clark Medal to Edwin Loy Hall, of Cleveland, Ohio, "In consideration of his many contributions to the gas industry, in the improvement of old processes for gas manufacture, for the development of new processes for the production of valuable by-products by the pyrolysis of petroleum oils, and for the invention of a new and more efficient process for the production of high heating value gas as a substitute for natural gas."

JOHN FRAZER,
Secretary to Committee

MEMBERSHIP

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS, MAY 21, 1952

HONORARY

Wolfgang Pauli, Ph.D.

ACTIVE FAMILY

William C. Dorn
Harry Garrett
Pasquale Lerro
Marcus A. Markley
Paul P. Perilstein
Maurice Salwen

ACTIVE

Ralph E. Bailey
Gordon A. Block, Jr.
E. Stephen Brotzman
Ernest E. Brown
James S. Bryan
Stephen Bukata
Edgar R. Burgin
William D. Connon
Robert S. Dahlberg, Jr.
Andrew J. Dahlke
Morse DellPlain
Joseph B. Donnelly
Perez Epstein
Samuel Genel
William A. Hodes
William H. Jackson
Samuel Ostrolenk
Walter H. Petri, Jr.
Edward L. Rademaekers
Francis A. Sanders
Alfred L. Test
William S. Weil, Jr.
Frank J. Zurzola

ACTIVE NON-RESIDENT

Karl B. Lutz

NECROLOGY

Harry Hudson, M.D. '44
A. Leith, Jr. '44
Brooks Parker '36
Harry M. Pflager '43
Harry Williams, Jr. '36

MUSEUM

It is impossible to tell when the first mechanical clock was made. The word is derived from the old-French word "cloque," meaning a bell, but as some of the clepsydras, or water clocks, had been made to ring bells, an early reference to a clock might refer to one of these and not to anything in the nature of clock as we know it today.

Probably the most famous of all clocks is that in Strasbourg Cathedral. Although it is generally spoken of as *the* astronomical clock few people realize it is the third of its line. The first Strasbourg Clock dates from 1352. It consisted of a perpetual calendar, an astrolabe, figures of the three wise men and the Holy Virgin carved in wood, and a cock. At the stroke of each hour the Magi bowed to the Virgin, the cock crowed and flapped its wings. There was also a small set of chimes.

By the year 1500 this old clock had fallen into a state of disrepair, but it had brought such fame to the city that the magistrate decided to have it replaced. This second clock was entirely new and much more elaborate. It so pleased the Pope when he learned of it that he ordered its maker, Habrecht, to make one like it on a small scale. This smaller clock is still in the British Museum—still running!

The second clock incorporated most of the features to be found in the present clock, which is the third. On one or more occasions it was struck by lightning but not until 1818 was it reported to be totally out of order.

But Strasbourg without a cathedral clock seemed to be incomplete, so that it was decided to place a new astronomical clock in the frame of the old one. The work was entrusted to Jean Baptiste Schwilgué, a native of Strasbourg, who was occupied upon it for four years.

A model, one quarter size, of this clock is displayed in the Astronomy Section of the Museum through the courtesy of the John Wanamaker Company. The original is 30 feet high and 15 feet wide. There are a few minor differences in the model, but the description which follows applies to details which may be seen in the Museum's model.

On the left is a Gothic pillar which contains the weights which keep the clock running; it is surmounted by the cock that has been a feature of all three Strasbourg clocks. Three panels on this pillar bear the portraits of Urania, Copernicus, and Schwilgué. In front and at the bottom is a celestial sphere. This globe turns so as to show sidereal time and the time of the rising and setting of the stars. Behind the globe is a calendar dial which indicates the fixed and movable church feasts. On the left of this dial other chronological letters and cycles are indicated. Above the calendar is a small gallery where the gods that symbolize the day of the week appear in rotation. On Monday it is Apollo, on Tuesday Diana, with Mars, Mercury, Jupiter, Venus, and Saturn following on successive days. Over this is a dial which indicates mean and Philadelphia times. Above this is an orrery showing the seven planets that were known at the time the clock was constructed. A step higher is a sphere showing the moon's phases.

We now arrive at two galleries which are a source of unfailing delight to young people. In the lower one appear four figures representing the four ages of man. These denote the quarter hours. During the first quarter of the hour the figure of a child occupies the opening, but as the clock strikes the quarter the child retires and his place is taken by the figure of a young man, to be replaced at the half hour by a warrior, and by an old man for the last quarter. In the upper gallery is the seated figure of the Saviour, but on the stroke of the hour, the twelve apostles come into view, make obeisance, and retire. At the same time the cock flaps its wings and crows.

Visitors to the Museum who are accustomed to the marvels of the machine age very frequently express astonishment at the ingenuity and craftsmanship displayed in this old clock, the Maillard automaton, and the other exhibits of a similar nature which pre-date machine made articles.

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open on Mondays, Tuesdays, Wednesdays and Fridays from 9 A.M. until 5 P.M.; Thursdays from 2 P.M. until 10 P.M.; Saturdays from 9 A.M. until noon.

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RYDER, FREDERICK L.: Network Analysis by Least Power Theorems.
MINORSKY, N.: Stationary Solutions of Certain Nonlinear Differential Equations.
TOMOVICH, RAJKO: A Universal Unit for the Electrical Differential Analyzer.
SHAW, M. C.: A Yield Criterion for Ductile Metals Based Upon Atomic Structure.
BURROWS, W. H.: Some Properties of Hyperbolic Coordinate Systems.
SILBERSTEIN, LUDWIK: Properties of an Exponential Size-Frequency Distribution of Finite Extent.
POLNAUER, FREDERICK F.: Bio-Mechanics—A New Approach to Music Education.
MOON, PARRY AND DOMINA EBERLE SPENCER: Separability in a Class of Coordinate Systems.

THE FRANKLIN INSTITUTE

exists today because of the faith and generosity of the men and women who for 128 years have given time and money to its support.

The Institute welcomes financial gifts and bequests and hopes that all those who desire to perpetuate its work will make the The Institute one of their beneficiaries.

FORM OF BEQUEST

*I give and bequeath to The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, the sum of*_____

BOOK REVIEWS

AERODYNAMICS OF THE HELICOPTER, by Alfred Gessow and Garry C. Myers, Jr. 343 pages, illustrations, 14 × 22 cm. New York, The Macmillan Co., 1952. Price, $6.00.

This reviewer continues to be delighted by the excellent texts on the various specialized subjects in aeronautical engineering theory and design to appear on the market in recent years. The relatively new and rapidly expanding field of helicopter aerodynamics and design has created many gaps in the essential background of student and graduate aeronautical engineers and the busy practicing aeronautical engineers in allied fields who are merely conversant with the myriad aspects of rotary wing fundamentals. For the most part, the information presented screens and integrates a vast amount of theoretical and practical information on the subject in heretofore widely scattered, and in many cases unavailable, sources. As such, this book bridges many of these gaps in a concise and progressive manner; this is no simple task.

Since the authors' wealth of experience in the helicopter field was gained in the Flight Research Division of the Langley Labs. of the NACA, they were well qualified to assemble and organize the past and most recent rotary wing material into such a complete and practical guide in the theoretical and physical terms most useful to the student and engineer alike. An extensive bibliography of all NACA papers on the subject, as well as papers from other sources, is given in the appendix. In presenting the material, the authors have succeeded in illustrating physical concepts for those phenomena associated with rotating wings. Lengthy mathematical formulae and derivations are rightly avoided except where they are of prime significance, thus sidestepping the usual "padding" and consequent loss of meaningfulness too often employed in the past by many authors of technical publications of this type.

The book is divided into twelve major chapters. The initial chapters deal with the development of rotary wing aircraft, an introduction to the helicopter and an introduction to hovering theory. Next are chapters on hovering and vertical-flight analyses and those factors affecting the related performance, followed by a presentation of autorotation in vertical descent. The succeeding chapters are concerned with physical concepts of blade motion and rotor control, the aerodynamics of forward flight, forward-flight performance, the prediction and effects of rotor blade stall, an introduction to helicopter stability, and finally an introduction to helicopter vibration problems.

SAMUEL M. BERKOWITZ

THE CHEMISTRY OF SYNTHETIC DYES, Vol. I, by K. Venkataraman. 704 pages, tables, diagrams, 16 × 24 cm. New York, Academic Press, Inc., 1952. Price, $14.50.

This book extensively surveys the developments in the dyestuffs industry, the chemical processes involved in the manufacture of synthetic dyes, the methods of application, and the theories of color. Despite the rather broad scope of the book, it is presented in a readable style.

The building blocks on which the synthetic dye industry is based are listed, and their sources and manufacture are described in detail. Standard procedures for testing the purity of these primary compounds are included. The unit processes of organic synthesis such as sulfonation, chlorination, nitration and reduction, alkali fusion, etc. are discussed in some detail as they relate to the manufacture of dye intermediates. In a lucid, organized manner the author traces the synthesis of most of the common and uncommon intermediates.

Several chapters are devoted to the theory and measurement of color in which there is a discussion of the relationship between chemical structure and the colors emitted. He describes with little comment the various theories which have been presented to correlate the absorption spectrum of an organic compound with its chemical constitution. However, there is an extensive discussion of the theory of color in which he presents his own views.

The latter half of the book describes the chemistry, manufacture, and application of the dyes used in the textile industry. Detailed processes are not included, and are certainly beyond

the scope of this book, since it is primarily a survey. For the organic chemist interested in synthetic dyestuffs and their application, this book should be valuable and interesting reading.

S. MUCHNICK

THE ASTRONOMICAL UNIVERSE, by Wasley S. Krogdahl. 599 pages, plus 6 star maps, illustrations, 16 × 24 cm. New York, The Macmillan Co., 1952. Price, $6.25.

In a scientific field which tends to be ultraconservative it is refreshing to find a book with a new approach to the teaching of astronomy.

Textbooks in use, today, follow a certain format which is forbidding. Now comes a text which the author seems to have enjoyed writing and he has a faculty of passing this pleasure on to the reader. The result is a thoroughly new and interesting book which is uniquely readable.

In *The Astronomical Universe* the author has brought astronomy as up to date as the latest issue of the *Astrophysical Journal*.

The book is divided into five sections which deal with The Solar System, The Anatomy of a Star, The Stellar Population, The Organization of the Universe, and finally the Evolution of the Universe. The subject matter is skillfully arranged to fall into these niches.

Dr. Krogdahl has gone into great detail in some phases of astronomy which other authors relegate to the graduate astronomy class. As a result there is brought into the book a magnificent section on the mechanics of radiation. There is an explanation for the high coronal temperature. The radiation processes in the sun are fully described and finally the last section on the evolution of the Universe merits an award for its full coverage with the inclusion of the latest theories of cosmogony. It is the only astronomy text in which this reviewer has found a section on kinematic relativity.

There are minor errors such as the fixing of the birth of Christ at 4 B.C. The above event probably took place in 6 or 7 B.C. Also the lunar eclipse which immediately preceded the death of Herod took place on March 13, 4 B.C. The author states that oxygen is scarce on Venus. Has any trace of oxygen been detected in the atmosphere of this planet?

The Astronomical Universe is a well written, well compiled textbook and this reviewer plans to use it in his next class in astronomy.

I. M. LEVITT

COTTRELL: SAMARITAN OF SCIENCE, by Frank Cameron. 414 pages, 14 × 22 cm. New York, Doubleday & Co., Inc., 1952. Price, $4.50.

Mention of the name of Frederick Gardner Cottrell immediately brings to mind his association with electric precipitation. Challenged to furnish further information upon this remarkable man, few scientists would be able to recall any of his additional achievements. Absence of knowledge concerning their brilliant colleague is not due to any lack of accomplishments but rather to his extraordinary ability for self-effacement. A full length biography of Cottrell was needed to bridge the gap in the history of science between the pre-nuclear fission stage and the present atomic energy age. For it was Cottrell's perception and energy which secured financial support for Van de Graaf's generator and Lawrence's cyclotron which got those fundamental techniques through their experimental stages.

Cottrell began his career as a teacher, but whether he was a good teacher is open to doubt. For in a talk designed to assist and inspire a student to complete a task, his prolific mind would produce so many ideas that the discouraged student would find himself confronted with sufficient labor to last throughout a normal life-time. It was during his tenure of this professorship of physical-chemistry that he began his work in electric precipitation of smoke, dust, and fume, and the recovery of valuable material from them, which led to a career in the Bureau of Mines and the Department of Agriculture. He worked on helium research during World War I and found himself under the cross-fire of the Army and Navy who were independently engaged upon the same task. Later, he had the discouraging experience of being caught in the political vicissitudes surrounding T.V.A.

However, these were incidents in a career that was as varied as any scientist could wish for. The complications were largely of his own making, for he could never say no to anyone who was in need of help, and the applications were many, for the expression "Ask Cot" was traditional among his friends and acquaintances. He was possessed of a rampant idealism. Not only did it cause him to reject repeated offers of highly remunerative positions in industrial laboratories, but it was admirably displayed in his generosity in assigning the electric precipitation patent rights to the Research Corporation for "the advancement of technical and scientific investigation and experimentation."

Cottrell's life is interesting for other than his scientific achievements. Mr. Cameron has handled a somewhat unmanageable mass of material with journalistic skill. He has contrived to work into his book so much material from Cottrell's diaries and letters that much of it is autobiographical. Many of the subject's letters written during his Munich student days reflect his thoughts on non-scientific matters, and may be said to reflect his philosophy. To write the biography of a man who was an irrepressible good samaritan: who had an enormous capacity for work and who worked like a man possessed; whose life was rich in accomplishment and yet bristled with foibles that called for sympathetic understanding, required courage. But Mr. Cameron, who is a free-lance journalist, has performed his task in a praiseworthy manner.

T. C.

CONFORMAL MAPPING, by Zeev Nehari. 396 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1952. Price, $7.50.

The material is presented so as to serve as a college textbook for a beginning course in Conformal Mapping. A good working knowledge of advanced calculus is required for a complete understanding of the text. The author builds upon this assumed background by introducing the reader to potential theory and complex function theory in the first four chapters which he suggests are suitable for a one-term first course on functions of a complex variable. The remaining three chapters are suggested as basis for a one-year graduate course in Conformal Mapping. Exercises are supplied and teachers adopting the text should work some out in class as examples, since the book does not supply them otherwise. In keeping with the author's concept of a text, no references to the literature have been given. From this reviewer's point of view the sooner this concept of a text is discarded the better, especially since the text is aimed not only at the pure mathematician but also at the more practical interests of engineers, physicists and applied mathematicians who are concerned with the actual construction of conformal maps. If the latter group is disappointed at the lack of examples and references, the former may find fault with the simplified proofs. Nevertheless, Professor Nehari has stated his aims clearly—to bridge the gulf between the theoretical and the more practical approach and to do so as simply and clearly as possible. The resulting book is surprisingly rigorous and yet as concise as a treatment of such a subject permits.

The text treats Harmonic Functions, Analytic Functions, The Complex Integral Calculus, and Families of Analytic Functions in the first four chapters. The last three are entitled Conformal Mapping of Simply-Connected Domains, Mapping Properties of Special Functions, and Conformal Mapping of Multiply-Connected Domains.

D. B. HOUGHTON

PRACTICAL INDUSTRIAL ELECTRONICS, by F. A. Annett. 381 pages, diagrams, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1952. Price, $5.50.

Practical Industrial Electronics attempts to explain the operation of numerous electronic devices without the use of a single equation or mathematical relation of any kind. To do this the author has had to resort to a large number of schematic illustrations and analogies. As might be expected, this method of teaching is cumbersome and, with only a few hundred pages in which to treat the subject, limits the scope of the book.

Practical Industrial Electronics has only descriptive value and can not claim to be of any assistance in constructing even the most elementary circuit. This is true because there are

no sample values assigned to any of the parameters in the circuits that are presented, nor are any of the relations given by means of which the parameter values could be computed. Although some general concepts of the functioning of various types of electronic apparatus can be gained, it is questionable whether the volume would be of very much use to the person charged with servicing any given equipment. These are usually the two main concerns of technical personnel: construction and servicing.

In order to give definite and helpful information on electronic circuits for the practical man's use, the handbook approach is more likely to be useful than the purely descriptive treatment. Some indication should also be given that will prevent the misimpression that control circuits are straightforward and foolproof in their operation. There is a tendency toward oversimplification when discussing control circuits by means of the descriptive method. Since automatic control devices frequently exhibit instabilities and require expert engineering analysis to insure success, this type of circuit should be avoided in the "practical" treatment.

Although the accepted convention regarding current flow and electron flow is somewhat unfortunate, it would seem unwise to write a book taking upon oneself the responsibility for changing this notation. The author's having done this in the greater part of his book may eventually confuse the student in attempts to understand more complex circuits.

The author has definitely limited his book to the so-called "practical" man, for he refers rather dubiously to the "high-browed physicist." This may have been an unfortunate point of view for the author to have taken and for the publisher to have permitted. It would have been better had the book been addressed to all who are not electronic circuit specialists, thereby including a much larger audience. Many chemists, mechanical engineers and physiologists, to mention only a few categories, are anxious to obtain some basic knowledge of electronic equipment. These non-electronic specialists are finding more and more need for electronic accessories in their work, and consequently desire information on the subject.

Evidence of this last point has been demonstrated at The Franklin Institute Laboratories where great interest was shown in a course of electronics for non-electronic engineers. Emphasis in this course, as in Mr. Annett's book, is on practical electronics, but it is directed at the broad variety of professional and non-professional prsonnel comprising a large research and engineering organization. With only a slight shift in viewpoint, it would have been possible for this book to reach a much larger audience than the installation, operation and maintenance men to whom it is addressed.

C. W. HARGENS

GRAPHIC AIDS IN ENGINEERING COMPUTATION, by Randolph P. Hoelscher, Joseph Norman Arnold and Stanley H. Pierce. 197 pages, diagrams, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1952. Price, $4.50.

Engineers and designers who are often confronted with myriads of engineering computations have found nomograms and other graphic aids to be of an invaluable assistance in the solution of their problems. The use of nomographs affords a means of readily ascertaining the relative weights of the various constituents of an expression. In dealing with a large number of combinations of the variables, it is not always feasible, nor is it generally desirable to make a detailed investigation into the variations due to a change in any of the parameters. This finds particular emphasis in the case where an optimum combination is being sought or a certain ratio is to be held within the realm of physical limitations.

In no part of the text do the authors imply that there is contained in this volume any advances in the art of nomography, however, their efforts have been directed toward the propagation of the use of nomographs and other graphic methods through a better understanding of the potentialities and applications of these devices. The material is presented in such a manner as to make it a fitting addition to the normal engineering curriculum. Each of the seven chapters follows a logical sequence, starting with the slide rule and continuing through to a treatise on movable-scale nomographs. Examples and problems are profusely injected throughout the book, thus increasing the usefulness of this as an engineering text.

There has been brought together in this volume material which has heretofore lost much

of its significance because of the secondary role it has played in previous texts. Graphical calculus and the extraction of empirical equations from data are too often brushed over lightly, whereas the authors of this book have placed a more proper emphasis on these subjects in view of their rising importance in the engineering world.

T. J. BOWDEN

ELECTRICAL PHENOMENA AT INTERFACES, edited by J. A. V. Butler. 309 pages, illustrations, 14 × 22 cm. New York, The Macmillan Co., 1951. Price, $6.75.

This book is a successor to Butler's earlier *Electrocapillarity—The Chemistry and Physics of Electrodes and Other Charged Surfaces*. Actually the scope of the work has been very much expanded, and the present book is a cooperative effort on the part of seven different people in the field. The various chapters of the book have been written by those qualifying for the particular material covered in the chapter. Thus, Butler himself has contributed the chapters on electrode potential, the electrical double layer, concentration polarization, and the behavior of oxygen and hydrogen at electrodes. Other chapters discuss electrokinetic effects, electrophoresis of proteins, electrokinetic behavior of ionic crystals, colloid stability, overpotential, membrane potentials and the electrical properties of living cells, nerves and muscle. It is especially interesting to find discussions of the biological aspects of this field, since this is probably one of the best places for the application of physical chemistry to problems in biology.

The book is a detailed report on the subjects that have been covered. It contains details of experimental techniques, representative data, and leading theories. The discussions are more than just summaries; critical reporting of the theories given leads to excellent discussions of the subject matter, but can make it hard going for those who are not well versed in the field. In spite of this, and if one is willing to go through the work of following the argument, the book should be of interest to physical chemists in general, since it contains a good survey of the subject not found elsewhere. Needless to say, it should be very valuable to those workers in the field because of its critical and comprehensive nature.

ALAN D. FRANKLIN

BASIC ELECTROTECHNICS, by B. L. Goodlet. 247 pages, diagrams, 15 × 22 cm. London, Edward Arnold & Co.; New York, Longmans, Green & Co., Inc.; 1951. Price, $4.00.

The author has included such material in this book as is required to present a basic course in electromagnetic theory. With this stated use, he has arranged the subject matter in a logical sequence. Approximately 250 pages have been divided into six chapters. Their titles are: (1) Steady Electric Currents; (2) Electrostatic Fields, Condensers and Dielectrics; (3) Electrodynamics; (4) The Calculation of Magnetic Fields; (5) Alternating Currents; and (6) Maxwell's Equations and Electromagnetic Waves.

A prominent feature of this book is the use of the rationalized MKS units. Early in the text, a table of dimensions, units, and conversion factors relating the MKS and CGS units has been included. Since the author has forsaken rigorousness in derivation for lack of space, this table should facilitate the use of references (employing the CGS system) which have a more elegant or classical treatment of the subject.

At first glance, one may get the impression that the author has written the book with the uninitiated in mind. In reading through it, however, it is readily seen that the book has good depth while being quite concise. By and large, a knowledge of calculus is necessary to follow the subject matter since the development of mathematical relations is highly condensed. Those unfamiliar with calculus and willing to accept mathematical expressions without proof may get by. An aid to this end has been installed in the form of asterisks denoting the more difficult sections.

Furthermore, many practical aspects of the subject at hand are brought up intermittently throughout the text and in the form of explanatory footnotes. For instance, the procedure for plotting B-H curves with the aid of a ballistic galvanometer is presented. However, the method of displaying B-H loops on the screen of an oscilloscope might also have been included since, together, the two methods very effectively illustrate the mechanism of hysteresis.

It seems quite likely that the author is of the conviction that problems are an essential part of a book and no mastery of a mathematical subject is possible without working with it. A comprehensive array of problems (with answers) has been included in each chapter. These are preceded by a number of illustrative examples.

Those considering the use of this book may find it a good text for the properly designed course of study at the junior or senior level of undergraduate work. More strongly, it is suggested as an aid to a comprehensive review for those having studied electricity earlier in life and also as a reference for the fundamental aspects of electrical engineering.

E. A. FASKO

PRINCIPLES OF QUANTUM MECHANICS. NONRELATIVISTIC WAVE MECHANICS WITH ILLUSTRATIVE APPLICATIONS, by William V. Houston. 288 pages, 16 × 24 cm. New York, McGraw-Hill Book Co., Inc., 1951. Price, $6.00.

Professor Houston's book is a volume in the well-known International Series in Pure and Applied Physics. It is a graduate level textbook intended for teaching the subject matter and instilling in the student an appreciation for and a desire to understand published work in quantum mechanics. The style is deductive, highly expository, and well suited for classroom use; the numerous problems included in each chapter, in many cases, go beyond the material in the book, as they should in a text of this kind. The reader is expected to have: a working knowledge of "modern particle" physics and elementary mathematical physics, and the ready availability of a reference library.

The first third of the book, comprising the first of five parts, is devoted to formulating basic quantum mechanics in terms of Schroedinger's wave mechanics. Following an historical introduction which describes the experimental necessity for a quantum mechanics, two fundamental postulates are introduced as are the concepts of dynamical quantities and operator relationships. The groundwork thus laid out, Professor Houston then progresses to develop examples of characteristic states, approximation methods, and spin and the Pauli exclusion principle. The chapter on approximation methods outlines the most important procedures for determining states when the Schroedinger equation cannot be solved exactly.

The remaining four sections of the book are devoted to detailed expositions, with examples of the mutual roles which are played between quantum mechanics and these other fields—spectroscopy, collision problems, electrons in solids, and electromagnetic radiation. In each of these sections the author discusses the physical relationships which give rise to the application of quantum mechanics, still not at the expense of distilling the necessary mathematics.

This textbook will no doubt be in sales competition with other recent graduate level textbooks in quantum mechanics. Examination by this reviewer of the others has indicated that sufficient differences exist in emphasis of material and method of presentation to justify Professor Houston's approach. The several textbooks should complement each other for any well rounded graduate student program.

S. CHARP

OUT OF THE SKY, by H. H. Nininger. 336 pages, 16 × 24 cm. Denver, The University of Denver Press, 1952. Price, $5.00.

There is a certain fascination which surrounds a meteorite just as there is a thrill which accompanies the observation of a bright meteor across the night sky.

Meteorites are the only materials we can touch which did not originate on the earth and so in essence these chunks of cosmic matter are star dust. They play a crucial role in theories seeking to account for the formation of the solar system and in this role have assumed great scientific importance.

Until recently there has been little in book form which could be used by the scientist to enlarge his horizons in a meteoritic sense. The classic book on Meteorites by Farrington is almost 40 years old, while Olivier's "Meteors" is 27 years old.

Now there appears "Out of the Sky," a new and comprehensive book by the Director of the American Meteorite Museum, H. H. Nininger. In 28 years of organized research in the

field the author has done more to promote the search for meteorites than any other man. He has personally talked to thousands about the mechanisms of meteorite recovery. He is eminently qualified to write a book presenting a systematic approach to the study of meteorites and related phenomena.

"Out of the Sky" contains sections of historical interest and of spectacular interest. The size and composition of meteorites is discussed and their structure analyzed. Meteorites seem to contain the same elements in roughly the same abundance as the rest of the cosmos. The fascinating story of the Greenland meteorites is told. The author could have expanded this section to deal with the troubles encountered in moving these to New York.

A chapter on the weathering of meteorites—a very important phase in this study—is included. Meteorite swarms, clouds and finally a section on cosmological significance brings the book to a close.

The author merits a "well done" from his scientific colleagues for a serviceable, well written book on a vital astronomical topic.

I. M. LEVITT

ELIAS E. RIES, INVENTOR, by Estelle H. Ries. 369 pages, portrait, 14 × 22 cm. New York Philosophical Library, Inc., 1951. Price, $4.75.

Here is a narrative of frustration and disappointed hopes that can have few parallels in biography. Elias E. Ries was granted over 200 patents, many were of minor consequence but a few were by no means insignificant. After twelve years of litigation his claim to priority in the invention of the third rail in electric railroads was sustained in the courts. Seventeen years of legal battle were required before he established his right to the invention of the electrically operated elevator—too late to furnish the inventor with any financial reward. And so the tale runs on, a continuous struggle against poverty and non-recognition when some of his patents—crown bottle caps, for instance—should have secured an adequate income, while his major achievements in the street railroad, elevator, motion picture, and seamless tubing, should have produced a fortune for a man with business capacity. Ries had so little business sense that he was a ready prey for every kind of rascal. To his credit it should be said that he was often unable to take advantage of opportunity because he did not have the railroad fare. Yet when a great steel corporation generously invited him to fix his own price for the patent for seamless tubing, he loftily replied that his invention was too great to be entrusted to any one company. As a result, the returns were limited to what a few small licensees chose to pay him, which was neither large nor often.

Ries was an engaging oddity. He worked entirely alone, without collaborators or subordinates. He lived in a world of his own, although the author more than hints at the heartbreak such a life enforced upon his wife and daughter. The book is a fine and loyal tribute of an affectionate daughter for a self-less man with an inventive genius and who worked like a man possessed. The book does not pretend to be a scientific investigation into the nature and methods of Ries' work, but does present a behind-the-scenes account of the inventor's private life, with all its frustrations, disappointments, and heartaches. It is a sympathetic picture of a lonely man with nothing to support him but the affection of his wife and daughter. To have lived through such an accumulation of afflictions must have been a trying experience, but Miss Ries writes with little bitterness. One of the villains in her existence is the patent system.

T. C.

PRODUCTION CONTROL, by Paul D. O'Donnell. 304 pages, tables and charts, 15 × 23 cm. New York, Prentice-Hall, Inc., 1952. Price, $6.35.

Paul D. O'Donnell, Assistant Professor of Industrial Management, Boston College, has written an interesting and fairly compact volume on the many aspects of quantity manufacturing. In his book the case-history method of illustrating major principles is employed. This method of presentation adds a great deal of plausibility to a subject which might otherwise be dull and theoretical.

The book not only covers those actual factory methods and procedures necessary to production control, but it also gives the background of thinking and planning that is necessary to success in a new venture. Typical in the thoroughness of the author's background information is a section on the relationship of the engineering and product development activities to production. Methods of production forecasting are also shown to have a direct bearing upon the success of the manufacturing process.

It is well known that the success of any management function depends almost equally upon its methods of directing operations and upon its follow-up system for checking the response to these directions. It will also be recognized that there are many ways of conducting follow-up. This subject is given the place of importance that it deserves with an entire chapter devoted to follow-up methods.

The theory and practice of statistical quality control is treated in sufficient detail to provide a basis for instituting these methods in a medium sized operation. The operation of the Dodge-Roming Tables (for determining the minimum number of inspected items to insure an outgoing quality limit) is typical of the information presented.

Plant managers in small and medium sized firms, as well as foremen in the larger plants, could surely profit by this volume, particularly through a better understanding of their own department's relation to the other branches of the organization.

C. W. HARGENS

NOMOGRAPHY AND EMPIRICAL EQUATIONS, by Lee H. Johnson. 150 pages, diagrams, 15 × 24 cm. New York, John Wiley & Sons, Inc., 1952. Price, $3.75.

The book is divided into two sections. In the first, methods are explained by which equations of various types can be represented in graphical form. The charts for such graphical solutions are called nomographs. The second part is concerned with determining empirically an equation closely fitting a given set of points. Considerable use is made of semi-logarithmic and log log paper so that the resulting graphs are straight lines or the desired equations are linear. The principal advantage of a nomograph cited is in the saving of time possible by providing simple graphical solutions to problems that otherwise would require considerable computing work.

The author has written an elementary book requiring little background. Though use is made of logarithms and analytic geometry, the book is understandable to those without such training. Ample figures, examples and exercises are supplied. It is supposed that a slide rule will be used. Not even a desk calculating machine is assumed available, though for a large number of points such an aid might save time in the long run. In that event, more mathematical treatments should be referred to.

In the part on curve fitting, methods are suggested for determining the general type of curve that will fit the given points and three methods are explained for determining the constants in the equations of the curves. They are the method of selected points, the method of averages, and the method of least squares.

Chapters in *Nomography* are Introduction, Parallel Scale Nomographs, Z-Charts, Parallel and Perpendicular Index Lines, Concurrent Scales, Recurrent Variables and Combined Nomographs. After a general discussion of the methods of curve fitting, the second part is concluded by three chapters on Curves of Two, Three and Four Constants.

D. B. HOUGHTON

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION

ELLICE McDONALD, DIRECTOR

***Abstract of* Choline Oxidase Activity in Rat Liver during 3′-Methyl-4-Dimethylaminoazobenzene Carcinogenesis.**—G. E. WOODWARD (*Cancer Research*, 11, 918 (1951). The rate of oxidation of choline at pH 7.8 in liver homogenates from rats on a carcinogenic diet containing 3′-methyl-4-dimethylaminoazobenzene (3′-Me-DAB) has been found to be about 25 per cent of that in homogenates from normal or control rats. The retardation in activity was almost as great after 14 days of feeding 3′-Me-DAB as after more prolonged feeding. The activity in the liver tumor homogenates was less than 5 per cent of that in normal or control liver homogenates and less than 20 per cent of that in 3′-Me-DAB liver homogenates.

3′-Me-DAB liver or liver tumor homogenates, at pH 7.8 or 7.2, produced predominantly more betaine aldehyde than betaine as the end-products of the oxidation of choline, while normal or control liver homogenates produced only betaine. At pH 6.7, 3′-Me-DAB liver and liver tumor homogenates produced little or no oxidation of choline, even to the aldehyde, while normal and control liver homogenates produced both betaine aldehyde and betaine.

CURRENT TOPICS

Industrial X-Ray Films.—In recognition of the increasingly important role of radiography in industry—for non-destructive testing, diffraction analysis and similar applications—Ansco, Binghamton, N. Y., a Division of General Aniline & Film Corporation, now offers, for the first time, a complete family of Industrial X-Ray Films. These films will meet the diversified needs of the industrial and scientific radiographer, can be used with low or high KV X-Ray exposures or with radium or cobalt gamma radiation, and can be relied upon to give brilliant radiographs of high diagnostic quality.

The complete Ansco X-Ray Industrial Film line is designated as follows: Ansco Superay "A" Film; Ansco Superay "B" Film; Ansco Superay "C" Film (a non-screen type film) and Ansco High Speed X-Ray Film.

Ansco Superay "A", which has been on the market for several years, now features an improved surface . . . a tougher, smoother overcoating to withstand the rigors of industrial use, thus minimizing abrasion, smudging and contamination which might lead to incorrect evaluation. It is especially suited for industrial uses where the recording of small defects and fine structural detail is essential. The inherent high radiographic contrast of Superay "A" will produce excellent radiographs where gamma radiation with cobalt or radium is employed to check pipe welds or complete castings. It is also recommended for certain types of diffraction analysis requiring fine definition.

Ansco Superay "B" X-Ray Film, re-introduced for the first time since before World War II, has the finest grain and highest contrast of any film in the Ansco Industrial X-Ray group. It is especially designed for use when optimum radiographic definition, sharpness and contrast are desired in preference to speed of recording. If radiographs are to be examined under magnification, the extremely fine-grain characteristics of this film assure clarity of definition.

Ansco Superay "C" is a new non-screen X-Ray Film. It provides maximum speed with the best practical balance in contrast and grain size when used without screens. It is particularly adapted for industrial radiography where rapid exposure, moderately high contrast and good detail are demanded to satisfy routine inspection requirements. It will find wide application in the examination of heavy metal castings, forgings and weldments if minimum exposure times are of great importance. Superay "C" fills the need for a fast film for direct-radiation exposures; registers X-rays generated at voltages up to 2000 KV; records gamma rays from radium or radioactive isotopes; offers controllable contrast, and maximum speed of recording in X-ray diffraction analysis.

Ansco High Speed X-Ray Film is recommended for those industrial applications where (*a*) exposures are normally made with screens of the Calcium Tungstate type; (*b*) where X-ray equipment of limited output is employed and material to be X-rayed is of excessive thickness. It is ideally suited for use in mass radiography of light metal castings of moderate thickness utilizing

moderate voltage techniques. Used with screens this film has excellent resolution and wide latitude, and will faithfully record detail over a considerable range of material thicknesses.

"Blotter" Analysis for Plastics.—Dr. James H. Freeman, a scientist at the Westinghouse Electric Corporation's Research Laboratories, has found a new analytical method of determining the chemical composition of Bakelite-type plastics.

The "Blotter" technique—more precisely called paper chromatography—was first used by chemists 100 years ago. In the last decade it was revived and used in the study of proteins. Only within the last year, however, has the method been applied to the study of phenolic resins and plastics.

Everyday items made from these Bakelite-type plastics include: radio and television cabinets, electric light switches, telephones, electric fan blades, the handles on electric irons, and bearings for many machines. Dr. Freeman's new analytical tool will have particular application in the development of insulating resins and varnishes for Westinghouse equipment.

Here is how the paper chromatography technique is applied: A strip of white blotter-like paper is suspended in a large glass jar about two feet high. Pinpoint samples of known and unknown ingredients of a phenolic plastic are placed at intervals along the top of the paper. The top of the strip is held in a glass trough filled with a solvent capable of dissolving the samples. More of the solvent is kept in a small dish in the bottom of the jar to keep the air inside saturated.

In much the same way that a blotter corner draws ink from a spilled drop, the solvent begins to "run" down the paper and carries the ingredient samples with it. After 15 or 16 hours, the solvent "front," or its leading edge, has nearly reached the bottom of the paper which still appears white. However, when an "indicator" chemical is "painted" on the paper, different colored spots appear. Their position on the paper enables the scientist to identify them. The color of the spots serves as an additional check.

Dr. Freeman said the primary value of this method of analysis when applied to resin chemistry is that it provides a specific and highly sensitive technique by which given substances including some previously unknown ones may be separated and identified.

New Type Askarel.—A new improved askarel for power transformers and load centers has been developed by the General Electric Company. The new liquid, patented by the Company as 1470 Pyranol, is a result of 11 years of laboratory research and field tests conducted by the Company.

The new 1470 Pyranol has improved technical characteristics, such as lower viscosity at lower temperatures and a lower pour point, allowing easier handling and application under adverse weather conditions. Advantageous qualities of the Company's earlier 1467 Pyranol have been retained in the new product, including non-inflammability.

Use of askarel in power equipment eliminates the necessity of fireproof vaults and long secondary runs of copper, thereby resulting in substantial savings. Low maintenance costs and less noise are other advantages of Pyranol units.

Pyranol 1470 and Pyranol 1467 are completely miscible and can be used interchangeably in existing equipment.

Coughing Iron Lung (*NYU Research Review*, Vol. 2, No. 1).—Making an iron lung cough may sound like a strange occupation to most of us, but it was one of the assignments given to engineers of the New York University Engineering Research Division. The purpose of the project was to bring relief and aid to some paralyzed victims of poliomyelitis, tuberculosis, and other respiratory diseases.

When a patient suffers from one of these diseases, thick mucous secretions gather in his lungs and bronchial tubes. Usually the mucus does no harm, since the patient promptly coughs it up. But if his chest and diaphragm are paralyzed so that he cannot cough, the mucus piles up until it interferes with his breathing. Every year some patients die, literally drowned by the secretions in their lungs.

The idea of the coughing iron lung originated with Dr. Alvan L. Barach of Columbia University who initiated the work on the coughing iron lung, then brought it to the Research Division for improvements in design and operation.

Basically, the lung simulates the physical forces that occur naturally in a vigorous cough. It consists of two pressure sections, a head section and a chest section. The sections are divided by a wall, with a small opening near the neck. The chamber is pressurized from the head end. After a few seconds, both sections are in equilibrium at pressure greater than that of the atmosphere. To make the lung cough, pressure at the head end is decreased very suddenly. It escapes rapidly to the room, so that the head is almost immediately at room pressure. The higher pressure in the chest section also tries to escape. In doing this, it compresses the patient's chest, simulating a cough, and bringing the mucus up out of the lungs.

After trials had proved that the lung worked safely and effectively on human beings, a unit was set up at Willard Parker Hospital and operators were trained in its use. The first medical use of the coughing lung was in October 1950, when it saved the life of a 21-year old girl suffering from bulbarpoliomyelitis complicated by collapse of a major portion of her lung. In fifteen minutes the girl's upper respiratory tract was cleared out and she went on to make a good recovery from the polio.

Since then, the new type of mechanical lung has undergone a series of clinical trials that indicate that the principle of the mechanically-induced cough will be useful in poliomyelitis, bronchial asthma, atelectasis of the lungs in adults and the newborn, and in other diseases where inadequate removal of bronchial secretion occurs.

The National Foundation for Infantile Paralysis has granted the Engineering Research Division a contract for the design and construction of an improved, all-purpose mechanical respirator embodying the cough chamber feature. The new lung, which will work on 110-volt current, will operate from the head end as well as the body end, and will be capable of providing equalizing pressure respiration as well as mechanically-induced coughing. It will be a side-opening chamber, for quick opening and closing. The improved model will be in transparent plastic, to help relieve the patient's sensation of claustrophobia.

Ultrasonic Viscosimeter.—Rich-Roth Laboratories, East Hartford, Conn., announces the "Ultra-Viscoson" for continuous, automatic viscosity measurement using ultrasonics. Hermetically sealed probe, the size of a fountain pen, has no moving parts, operates to 650 F., 10,000 atmospheres pressure, is installed permanently in pipe lines, production kettles or used in test tubes and beakers. Electronic computer, located up to 1 mile from probe, indicates viscosity of Newtonian materials from 0–50,000 centipoises × grams/cc. in 4 decades;—0/50/500/5000/50000. Apparent viscosity of non-Newtonian materials measured over much greater range. Connection to recorder or controller provides continuous charts or automatic control. The Ultra-Viscoson is used for manufacturing and research in petroleum, resins, paper, plastics, starch, gelatine, foods, textiles, soaps, printing inks, coatings, finishes, blood plasma substitutes and medicine.

New Source of Illumination.—A new source of illumination by which materials are made to glow with cold light when an electric current passes through them was listed among a number of important recent advances in scientific research by Dr. C. G. Suits, Director of Research at General Electric, speaking before the Chicago section of the AIEE recently.

The G-E official said the new source of lighting is accomplished with an effect known as "electroluminescence," which was discovered in 1936 by a Frenchman named Destriau. He explained that this can be accomplished with a piece of glass coated with a transparent but electrically-conducting film, over which is placed a layer of a powdered "phosphor," like that which gives the light in a fluorescent lamp.

On top of this is placed a metallic film, making a sandwich of phosphor between two conducting layers. When these are connected to an electric current, the phosphor glows with cold light, rather than the type of light from the white-hot filament in the incandescent lamp.

At present, he stated, this kind of lighting is not efficient, but it is being actively studied. Two General Electric scientists recently reported that single crystals of the phosphor may be made to glow, yielding many times as much light as with the powder. This, he said, seems one possible way of improving the output of light from this source.

Ignitron Rectifier Locomotive.—A revolutionary Westinghouse electric locomotive so powerful that it recently hauled a record-breaking mile and one-quarter long train of 162 fully loaded coal cars—enough fuel to heat an average home since the year 1 A.D.—was described recently before the New York Railroad Club. W. A. Brecht, of the Westinghouse Electric Corporation, addressed the organization's annual electrical meeting and Dr. John A. Hutcheson, Westinghouse vice-president and director of research, spoke on the research aspect of such developments.

"Westinghouse has built two of these Ignitron rectifier locomotives," Mr. Brecht said, "and preliminary tests indicate they may hasten a revival of interest in railroad electrification."

He revealed that these first locomotives, said to be the only new type of electric motive power in the industry for the last quarter of a century, have been purchased by the Pennsylvania Railroad, put through their paces on extensive road tests, and are now in heavy freight service.

Mr. Brecht explained that the difference between this locomotive and any predecessor is its use of Ignitron rectifier tubes to convert alternating current from overhead trolley lines to direct current for driving its motors. While alternating current is easier and cheaper to transmit than direct current, d-c. driving motors have many operation and cost advantages. The Ignitron rectifier locomotive combines the advantages of both systems.

"With this new application of the Ignitron rectifier tube," Mr. Brecht told Railroad Club members, "the locomotive is economical to operate, has a continual and unlimited source of power, is easy and relatively inexpensive to maintain, is easier starting, smoother riding, powerful at slow speeds, fast enough for any requirement—and pound for pound no other machine in the world can match it."

He said the 6000-hp., two-unit locomotive is 124 ft. long, on six motored axles. It weighs 740,900 lb. The locomotive's tractive effort, or ability to pull heavy loads, is measured at 189,000 lb.

Gaskets That Block TV Interference (*Nickelsworth*, Vol. XVIII, No. 2).—Squiggly patterns of interference in TV and radar tubes can blot out half the picture. A plastics manufacturer in New York City learned the hard way how serious this inteference problem can be. The U. S. Coast Guard got a court order closing his plant when they traced interference 1000 miles away to his preform heaters.

By June 30, 1952, an F. C. C. order becomes effective against equipment that causes this interference.

Under suspicion are diathermy machines, dielectric mold heaters, welding arc oscillator currents, power plant generators, radio transmitting sets, and even the TV set itself. Preventive measures can require a complete cage of metal mesh, with electrical filters on all wires, leads, or pipes that leave the enclosure. Serious cases are also fitted with Monel knot metal mesh gaskets made by Metal Textile Corp., Roselle, N. J. These go around lids and parts in transmitting sets; into flanges of square waveguides that pipe micowaves around corners; and over instrument panel openings.

Quartz paper developed by the Naval Research Laboratory, ONR, can be manufactured cheaply from abundant domestic sources, may be substituted for higher-cost asbestos insulation material, withstands temperatures up to 3000 F. as compared to 1000 degrees for asbestos. Since quartz paper is boron-free, it may be used as insulation in components subject to atomic radiation, and in nuclear energy powerplants. Manufacture of quartz paper closely resembles conventional paper-making; in a recent test run with a Fourdrinier paper-making machine, paper five-thousandths of an inch thick was produced at a speed of 40 ft. per minute.

A new synthetic rubber insulation, designed to replace wool fleece and felt in combat boots, is being tested by the Quartermaster Corps. Present type insulation is sealed between two rubber layers, readily absorbs moisture if either is punctured, thus requiring prompt patching of any holes. Use of unicellular synthetic rubber is expected to make boot more resistant to puncture, is water resistant, makes immediate patching unnecessary if boot is torn. The new insulation is still in experimental stage, will not be standardized for general issue until field testing is completed.

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